Self-Contained Railway Motor Cars and Locomotives

SELF-CONTAINED RAILWAY MOTOR CARS AND LOCOMOTIVES

Prepared especially for the instruction
and training of students of the
American School

By

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INTRODUCTION

DEVELOPMENT OF TYPES

Long Period of Development. Since the advent of the steam locomotive, inventors and designers have turned their attention toward the production of railway cars in which the power plant is self-contained. All forms of motive power have been tried in many and various combinations: steam, with the flash boiler and high pressure—coal and oil fired; electric motors driven by storage batteries; compressed air; and the internal-combustion engine, with combination drives of every sort. These drives may consist of electric generators and motors, mechanical transmissions with spur gearing and clutches, electro-mechanical combinations, and friction drives. The hydraulic transmission has also been tried, but little has been done with it, owing, no doubt, to the fact that designers of self-contained cars are for the most part unfamiliar with hydraulic principles and their application to power transmission.

The self-contained cars of the past favored the steam engine design, with the engine mounted on the trucks and the boiler within the car body. This, of course, was an adaptation of the steam locomotive in smaller units to individual cars and was used before the internal-combustion engine was developed. This feature is still found in practically all the modern steam self-contained cars and takes from 10 to 15 feet of valuable space within the car body for engine room and does not permit a passage between cars when two or more motor cars are coupled together in a train. European countries have a number of these cars still in use and have been rather successful with them but are, however, rapidly adopting those using the internal-combustion engine, owing to its larger radius of operation and economies.

Adaptability of Internal-Combustion Engines. A number of forces or circumstances early destined the steam and compressed-air motor cars to give way to the more compact and easily handled internal-combustion engine type. A main reason for the rapid advancement of the internal-combustion engine is the fact that with it more power can be placed in a given space than with any other form of prime mover, and moreover its radius of operation and its economies surpass all others. It has, therefore, come to be looked upon as the only substitute for the steam engine and the only suitable motive power for self-contained railway motor cars and for a new type of locomotive.

Development Due to Automobile and Marine Service. Tracing the evolution of the railway motor car to the present date, it is to be noted that while the internal-combustion engine appeared early in the manufacture of these cars, it is only since 1908 that it has monopolized the field. Many experiments were tried before the engine arrived at its present state of development. This development has been largely due to the automobile and marine service which the internal-combustion engine has been called upon to do and which it has so ably performed. Railroad work calls for an engine that is quite different from those used in automobile and marine work, in that it must withstand the everyday shocks and knocks which a machine in railroad service receives.

Large Sizes of Units Possible. Internal-combustion engines using gasoline, fuel oil, distillate, or crude oil occupy a field in the marine service that few realize. So rapid has been their advancement that practically all new ships and submarines are equipped with them as their sole motive power. In fact, the submarine would not exist were it not for this compact source of power. In Europe several large ships of 18,000 hp., consisting of three units of 6000 hp. each, were constructed within the last few years. Each German submarine was equipped with four Diesel crude oil burning engines of over 1500 hp. each; in other words, each engine had as much power as the average steam locomotive. These facts serve to illustrate the sizes to which the internal-combustion engine has been designed with wonderful success. All new equipment, whether for railroad or any other

service, must first pass through a number of years of development, during which the design is being perfected and, of more importance perhaps, operators are being instructed and educated as to the machinery's use. Indications, therefore, point to the fact that the internal-combustion engine is at last coming into its own and today stands without a competitor in the field of self-contained railway motor cars.

MEANS OF TRANSMITTING POWER TO WHEELS

Several Types of Transmission Developed. A very important feature in the adaptation of the internal-combustion engine to railway car service is the method of transmitting the power of the prime mover to the wheels on the trucks. Hence study of transmission is absolutely necessary. It is a well-known fact that the internal-combustion engine does not possess the ability to start a load until the engine itself has attained a speed corresponding to the horsepower required to move the load; that is, the load cannot be thrown directly on the engine but must be applied gradually through some elastic medium. These mediums are as numerous as the types of valve gears applied to the steam locomotive and have not become standardized in any definite direction. However, the following descriptions cover the field fully and show the various combinations.

Mechanical Transmission. The conventional form of mechanical transmission includes a clutch to connect and disconnect the motive power to and from its load and an entirely separate change-gear for positively driving the axle at certain speeds. These speeds bear a definite relation to the rate of rotation of the driven members of the clutch. In starting and accelerating a heavy load, such as a railroad car weighing from 30 to 60 tons, it is necessary to cause the clutch to slip until the motive power can pick up the load, therefore, the full engine power cannot be utilized until the clutch is acting positively. This necessitates overpowering a car for a given service—that is, installing an extra large engine—and consequently the practice is a waste of capital and energy.

Electric Transmission. Electric transmission uses an electric power plant on a small scale. An electric generator is driven by

whatever motive power is used and the current generated transferred to the electric motors on the trucks. These are geared to the axles. In starting a car with this type of transmission, it is possible to obtain a fairly smooth and even motion of the car by varying the voltage and current, but it necessitates various switches and other apparatus. An electric motor in starting is no more efficient than the mechanical system and, in addition, it must not be forgotten that the final drive from the motors to the wheels is through gears.

Electro-Mechanical Transmission. An electro-mechanical transmission system, of which there are a few in operation, consists of a dynamotor connected to the motive power with or without a storage-battery auxiliary. The final drive is through gears to the axle. In starting, the dynamotor (generator and motor combined) is used in conjunction with the gears. After acceleration the dynamotor and gears are cut out and a purely mechanical transmission is employed to carry the load. When this system is used with storage batteries, great care must be exercised to prevent rapid deterioration of the batteries owing to the sudden reversals of the current.

Friction Transmission. The conventional form of friction transmission consists of two flat-faced discs with their planes at right angles to each other, the driving disc being held against the other with sufficient force to cause the driven disc to carry the load. These discs are usually held together by a compressed-air mechanism. The final drive from the driven disc to the wheels is through sprockets and chains. Excessive frictional losses occur in heavy transmission units of this type on account of the heavy pressures required to hold the discs together and the complicated final drive to the wheels.

Hydraulic Transmission. Hydraulic transmission is a system using oil as a power-transmitting medium and having a piston pump with a variable and reversible action to generate pressure. The pressure is transmitted through suitable piping to a piston motor, with a fixed stroke, mounted on the axles. The pumps and motors are always of multiple-cylinder construction. As no gears are required and the control is simple, hydraulic transmission should prove an efficient and reliable method of transferring motive power to axles.

FUTURE OUTLOOK

Lower Running Cost of Electric or Self-Contained Units. It is now a good many years since the railroad companies, realizing that they were incurring much unnecessary expense in running regular complete trains in branch and suburban service, endeavored to cut down expenses and, at the same time, improve and accelerate their train service, by installing a more flexible system.

Any railroad when spread out in plan represents a network with feeders radiating from the chief arteries of travel. One of the greatest problems of railroad managers at the present time is to prevent these feeders from actually showing a deficit. It is, indeed, a fortunate railway system which makes a profit over the cost of operation on the passenger receipts from these feeder and branch lines. The solution of this problem points to electrification or self-contained units.

Difficulties with Electrification. *Electricity Not Primary Power.* Frequency of service, high speed, general comfort of passengers, and increased service are advantages of independent electric units apparent to the lay as well as to the professional mind. These independent but expensive units are extremely adaptable and have proved very desirable. It must be remembered, however, that *electricity is not a primary power* and that, whether the steam locomotive or an electric car (using the third rail or trolley system) is employed for operating trains, *steam is still the primary power.* The advisability of using the one rather than the other method resolves itself into a comparison of two different methods of applying the primary power, namely, its direct application by the steam locomotive, which is notoriously wasteful and inefficient, or its indirect application by means of electric distribution from large centralized power plants.

Cost of Electrical Installations. The enormous cost of installation and maintenance of the electric system with its large power plants, accompanying substations, heavy copper feed wires and means for carrying them, rail bonding, and third rail or overhead trolley and the necessity of preparing safety devices against the dangers of the third rail have done much to prevent the general adoption of electrification. All these considerations, together with the doubt as to the reliability of the third rail or the trolley under

adverse conditions, their impracticability for switching and yard work, and the certainty that electrification will be supplanted by improved methods in the future, have up to the present time made the railroads hesitate to go to the expense of electrification.

Value of Gas Motor Cars. *Saving in Operating Expenses.* Turning now to the self-contained motor cars, the advantages are many. In the first place the cost per car mile of operating these self-contained units is about one-third that of the regular steam service, especially in England and on the Continent. It is apparent, therefore, that in running twice the number of daily trips with a gas motor car there will be an actual saving of about 30 per cent in operation costs, not to mention the convenience and the increased service for the passengers hauled.

Efficiency of Design. As to efficient design, certain of the gas motor cars have a great advantage over the present-day steam locomotive in tractive effort and drawbar pull. *With the steam locomotive, steam car, or any car using side rods, the loss in power transmission is seldom recognized.* The method of utilizing the adhesion weight of the locomotive on other wheels than the main drivers may be satisfactory so long as all the coupled wheels are absolutely of the same diameter. As soon as unequal wear occurs, however, inefficiency begins, and very serious inefficiency at times. Over twenty-five years ago tests showed that the losses resulting from this cause in the case of coupled wheels were nearly 50 per cent. The possibilities of utilizing, with the car or locomotive propelled by the internal-combustion engine, adhesion weight and tractive effort on all wheels, or on as many as may be necessary to give the desired acceleration, may lead, in the near future, to more effective results than with the ten drive-wheels of a "Decapod" locomotive.

European Adoptions of Self-Contained Motor Cars. In Europe, where necessity for economy is of vastly more importance, seemingly so at least, the railroads have for years been operating self-contained motor cars in all their various forms. The most onspicuous application of those using steam is on the Great Western Railway of Great Britain. On the Continent preference is expressed for the internal-combustion engine, noticeable among the adoptions being that on the Arad-Csanád Railway of Austria-Hungary.

The Wurttemburg street railway is the most aggressive of the foreign roads that have tried the independent motor car. It has experimented with storage battery cars, steam cars of the Serpollet type, and internal-combustion engine cars of the Daimler type. It is interesting to note that this road put an independent gasoline motor car into service over twenty years ago.

SELF-CONTAINED MOTOR CARS

STEAM CARS

General Features of Steam Equipment. At first thought, one might naturally suppose that the steam engine would be the most suitable power for self-contained railway motor cars as it is comparatively easy to apply and, on account of its boiler acting as a reservoir, its power may be used as needed within certain limits. The usual design of this equipment placed the engine and boiler on the leading truck. During the years 1906 to 1908 the steam motor car flourished but, owing to the troubles enumerated later, it died out in the United States as rapidly as it had sprung into being. England and France still operate quite a number of these cars in suburban service with considerable success. Fig. 1 shows typical English steam motor car equipment.

What has been done in reducing the fairly powerful steam locomotive into a small compact space for motor car service is strikingly shown in the accompanying illustrations, Figs. 2 and 3, for example, showing a Chicago, Rock Island and Pacific car, the power plant of which was built by the American Locomotive Company in 1908. For service purposes, this locomotive is properly put in comparison with the smaller types of standard locomotives used on branch lines and, while certain reductions have been made by lopping off waste space and, consequently, dead weight, the engine, with the car of which it forms a part, is, for operative purposes, the equivalent of the light locomotive mentioned.

Details of Rock Island Car. In the car illustrated in Fig. 2, the entire engine and boiler are carried on a four-wheel truck—the forward truck of the car—of which the rear wheels are the drivers. Of the total weight of 104,000 pounds, 64,000 pounds is carried

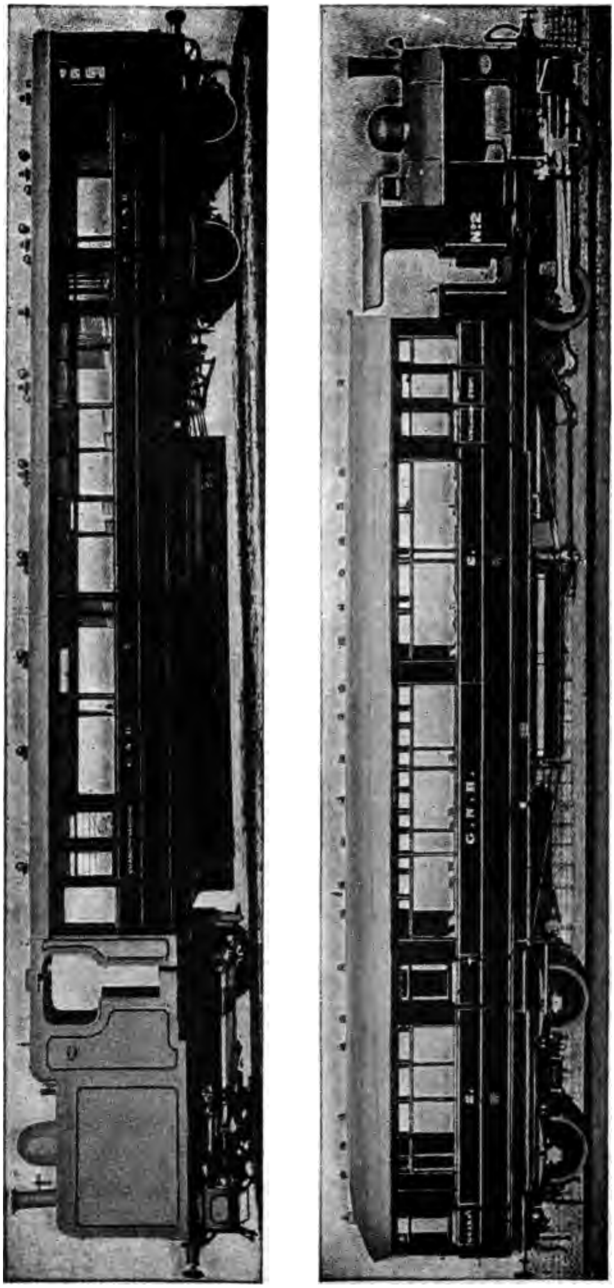


Fig. 1. Typical English Steam Motor Car Equipment

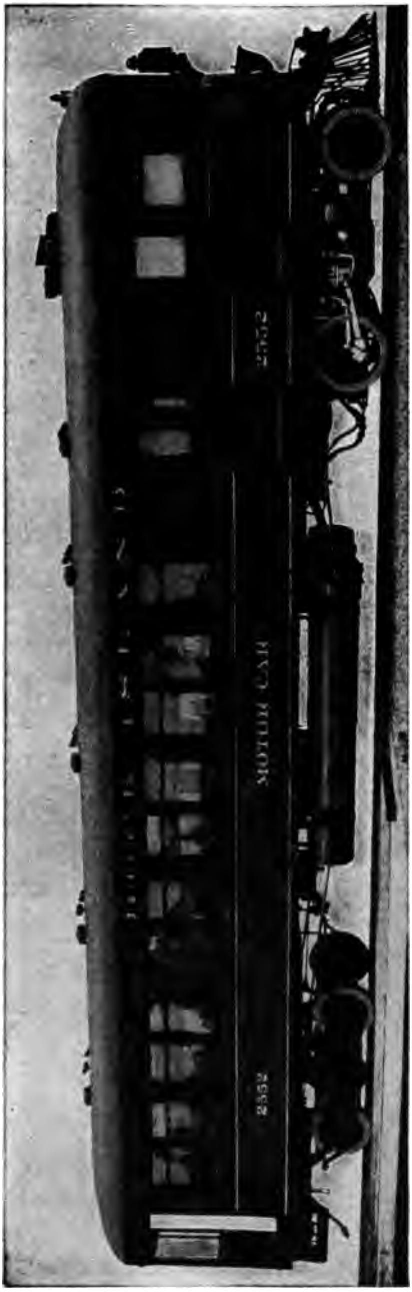


Fig. 2. Steam Motor Car of Chicago, Rock Island and Pacific Railway

on this truck and includes the boiler, the engine, and a certain percentage of the weight of the car body.

Engine. The engine, Fig. 3, is a two-cylinder cross-compound type, the cylinders being 9½ and 14½ inches in diameter with a 12-inch stroke. Both high- and low-pressure cylinders are equipped with piston valves operated by Walschaert valve gears. The rear wheels are the drivers and are 38 inches in diameter. Working compound, the engine will develop, theoretically, a maximum tractive power of 4360 pounds.

Boiler. Superheated steam at 250 pounds boiler pressure is supplied to the cylinders from a horizontal boiler of the return-tube type. In order to eliminate the necessity of flexible steam joints, the boiler is mounted rigidly on the motor truck frame. By the use of the horizontal return-tube boiler, the problem of providing the largest amount of heating surface possible within the necessarily limited amount of space has been solved satis-

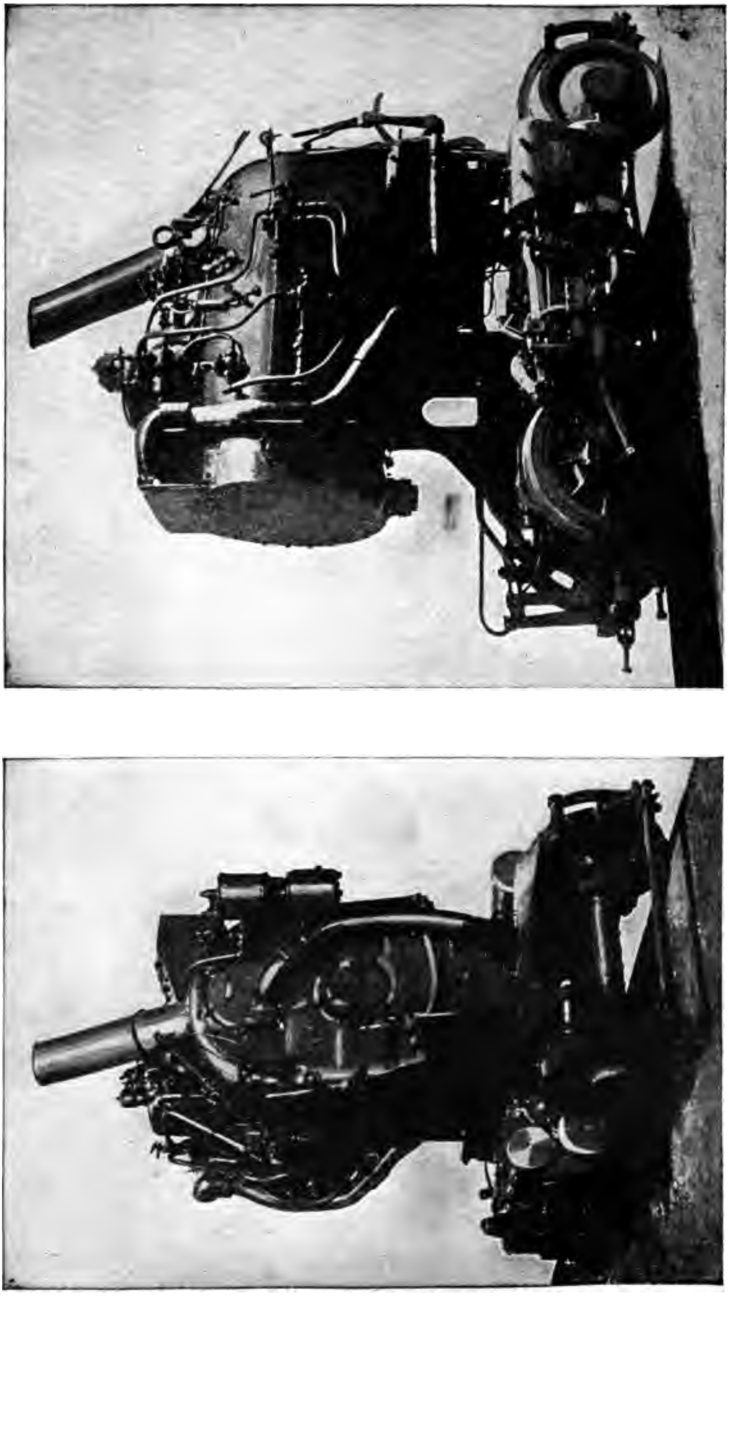


Fig. 3. Front and Side Views of Engine Used in Rock Island Car

factorily. The fire box is at the front end and the smoke box is directly above it. The gases of combustion pass through the tubes to the combustion chamber at the rear end of the boiler and thence forward through the return tubes to the smoke box. The fire box is 33 inches long and 43 inches wide and is bricked for burning oil as fuel. The barrel of the boiler is 45 inches in diameter. At the combustion chamber end there are 214 fire tubes $1\frac{1}{4}$ inches in diameter and 3 feet 9 inches long and an equal number of return tubes of the same diameter. The total heating surface is 565.6 square feet, of which the tubes contribute 528 square feet and the fire box the remainder. The boiler is fitted with a superheater located in the combustion chamber where the temperature of the gases is high.

Superheater and Other Accessories. The superheater header is bolted to a cast-steel saddle secured to the top of the boiler. The header is divided transversely into saturated and superheated steam compartments by means of a vertical partition, and there are sixteen superheater tubes bent in the shape of a double loop and extending down into the combustion chamber. Steam passes from the dome through a short dry pipe to the superheater and through it to the high-pressure cylinder, which is located on the right side of the truck.

The entire engine and boiler are contained within the wheel base of the truck, which is 8 feet 4 inches between wheel centers. As shown in Fig. 3, the locomotive is complete in every respect as to equipment of injectors, lubricators, gages, air-brake apparatus, and controlling gear. The construction of the car framing is such that the locomotive part can be detached from the car body for the purpose of general repair, though in its normal position it is entirely enclosed in the front compartment.

Kobusch-Wagnehals Car. The Kobusch-Wagnehals steam motor car, Fig. 4, built by the St. Louis Car Company in 1906, was one of the largest ever constructed, being 82 feet 2 inches over the pilot and 53 feet between truck centers. The weight on the drivers was 115,600 pounds and on the trailers 62,960 pounds, making a total of 178,560 pounds.

Engine. The motive power was a duplex horizontal engine driving the forward truck through spur gearing. Side rods con-

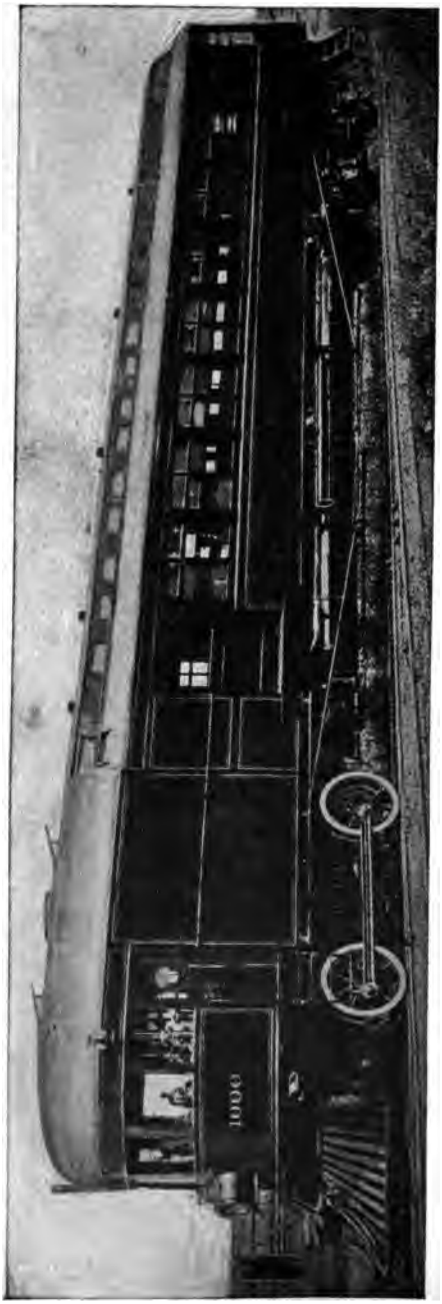


Fig. 4. Kobusch-Wagnehals Steam Motor Car

nected the front and rear drivers which had a diameter of 42 inches and a wheel base of 9 feet. Reversal of the engine was accomplished as on a steam locomotive. The cylinder end of the engine was supported on a ball-and-socket joint, permitting movement in all directions. The cylinders were 11 by 13 inches, having piston valves and being capable of developing 240 horse-power at the rails. The tractive effort was 8080 pounds and at not more than 5 m.p.h. (miles per hour) the car could haul on a level track, including its own weight, 538 tons; on a 1 per cent grade, 299 tons; and on a 2 per cent grade, 172 tons. On the level at a speed of 41.6 m.p.h., corresponding to an engine speed of 400 r.p.m. (revolutions per minute), the maximum load was 205 tons.

Boiler. The car was equipped with a marine type of water-tube boiler having a working pressure of 250 pounds per square inch, a heating surface of 1215 square feet, and a grate area of 43.5 square

feet, there being five burners for oil. The oil was fed to the burners under air pressure. Oil and water were carried in long cylindrical tanks under the car, these tanks being 30 inches in diameter and 30 feet long and having a capacity of 2000 gallons of water and 1000 gallons of oil. Ordinarily, the boiler was fed by marine pumps with a duplex injector as an auxiliary. The engine room occupied 10 feet of the car.

Disadvantages of Steam Motor Car. The above descriptions give some idea of the skill put into the design of the self-contained motor car using steam. However, steam for independent motor cars has serious drawbacks, of which may be mentioned the great weight of the engine and boiler; the space required by the water and fuel, which confines the radius of operation to comparatively narrow limits; the clogging, scaling, and corroding of the boiler and piping, which rapidly reduce their efficiency; the time required for taking on water, firing up, coaling, etc.; the constant attention required by the engine and boiler; the annoyance of exhaust steam; and the danger of bursting the boiler and piping which have to be kept under high pressure. The introduction of the flash boiler and liquid fuel was attempted in order to overcome some of these difficulties, but the flash boiler, though efficient in light automobile work, proved an utter failure for heavy railroad service.

The steam motor car, therefore, offered none of the advantages of increased travel, comfort, and efficiency demanded by the public and could hardly have been expected to compete with the trolley car. It has, in the United States at least, been entirely replaced by the internal-combustion engine.

STORAGE BATTERY CARS

Limits as to Power and Range of Operation. The storage battery car cannot exactly be classed with the self-contained railway motor car, as it is usually of very light construction and, having no reserve power in any form, cannot, when delayed, make up lost time. As a rule, the speed at which it operates is about 25 m.p.h. on level track. There is, however, a field for this car, especially where service is infrequent and the terminal points or charging stations are not more than 30 miles apart.

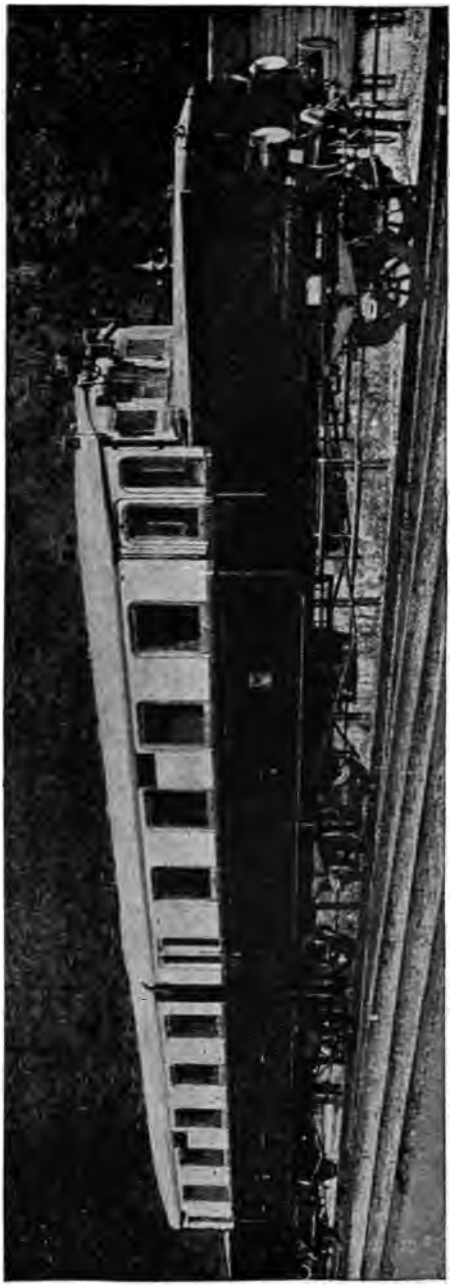


Fig. 5. Storage Battery Car Used on Prussian State Railways

Prussian State Railway Car. The short lines of Europe use a considerable number of cars of this type. Several cars were put in operation on the Prussian State Railways and met with considerable success for suburban service. The lines radiate from Mayence in three directions, viz., 11, 7.5, and 11 miles, respectively, from the main terminal, making a total mileage of 29.5. The cars are operated at speeds ranging from 20 to 30 m.p.h.

Type of Car. As is evident from Fig. 5, the car is of the side-compartment type and consists of six compartments, each with seats for ten persons, giving a total seating capacity of sixty. In its general construction the car resembles those used in the Berlin subways. It is mounted on three pairs of wheels of the ordinary kind, without trucks. Since there is a motorman's cab at each end of the car. it is unnecessary to turn the car at the terminals.

Batteries. The batteries are stored under the

seats in each compartment and were built by the Accumlatoren Fabrik of Hagen. Under each seat is placed two large boxes which are slid into place and are protected with the front board of the seat, the top of the seat being hinged for battery inspection. The two boxes contain 7 and 8 cells, respectively, making 15 cells under one seat and 30 in a compartment. The entire car holds 180 cells, which are ample for the grades and speeds on this line. The cells have a capacity of 230 ampere-hours at a 100-ampere discharge rate. With a single charge the 180-cell battery can take care of a 36-mile run when the running speed is 24 m.p.h., which is the maximum speed on these lines. With this capacity the car makes two round trips without recharging.

When the batteries are recharged, a flexible plug is fitted at each end of the car, the batteries not being removed except for repairs. The batteries may be charged in a single series of 180 cells or in two groups of 90 cells each in parallel. The cells are considerably larger than ordinary, being 15½ inches long and 5 inches high. Each cell weighs 156 pounds. There are four positive and five negative plates to the cell, these plates being separated by wood and gutta-percha strips and suspended on glass by means of lugs. The cell boxes are of wood specially treated and given an outer coating of acid-proof varnish. Connections are made to each cell by copper strips which, in turn, are protected by coatings of lead so that the fumes will not attack them. Special ventilation is provided to carry the fumes out of the car and at the same time provide a good supply of fresh air. The 180 cells weigh 10 tons and are capable of furnishing 68.5 kilowatt-hours on a single discharge. The life of the positive plate is estimated at 65,000 car miles and that of the negative at 40,000 car miles.

Electrical Equipment. The electrical equipment, including the motors and control apparatus, was built by Siemens-Schrickert. On the front and rear axles are mounted motors of 25 horsepower each, arranged to operate in series-parallel. These motors have a gear ratio of 1 to 4.3 and are said to give 84 per cent efficiency, each motor having a total weight of 4800 pounds, including the gears and casings. Each cab is provided with a full set of operating valves and gages and a control having nine running points

and four braking points. Braking is effected by short-circuiting the motors under different conditions. The resistances are mounted on the roof.

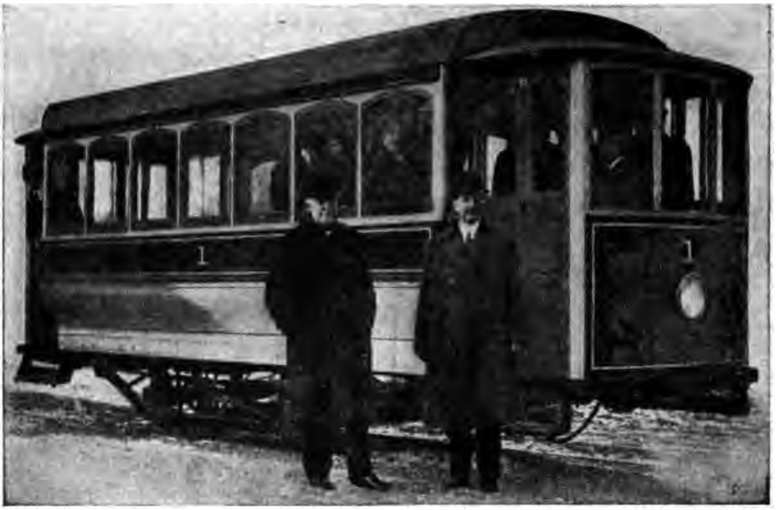


Fig. 6. First Beach-Edison Storage Battery Car

Each compartment is arranged with two electric lights and with electric heaters beneath the floor and between the seats. The car fully loaded weighs 22 tons, each motor 2.4 tons, and the battery 10 tons, making the total weight about 37 tons.

Fig. 7. Continental Type Car Built for Cambria & Indiana Railroad

American Railway Battery Cars. *Edison Car.* The first railway car operated with an Edison storage battery was placed in service in November, 1909, and later was used regularly in Brook-

lyn, New York. This car, Fig. 6, was of very light construction, weighing only 5 tons and equipped with independent driving wheels; it proved very successful for the service for which it was intended. An Edison car used by the Cambria & Indiana Railroad in Pennsylvania is shown in Fig. 7.

Havana Storage Battery Train. In 1912 a storage battery train, Fig. 8, was built for Havana, Cuba, each car being 38 feet over the platform buffers, 8 feet 3 inches wide, and 12 feet 7½ inches from the top of the rail to the top of the roof. The cars were equipped with 220 cells of the A–6 nickel-steel alkaline-type batteries placed under the transverse seats. Two hundred of these cells were used for power and 20 for lighting and for operating the multiple-control relays. Each car was equipped with four 10-horsepower 200-volt 37.5-ampere motors with speeds of 800 r.p.m. Two motors permanently connected in multiple were suspended, one from each axle of the truck, and the wheels were driven by a gear on the inside of the wide hub through a single reduction to the motor pinion.

The train was operated by a unique system of magnetic multiple-unit control and could be operated from either end of any car by a master controller placed on each platform. This master controller was fitted with a control and a reversing lever which were mechanically interlocked. Four speeds could be obtained from the master controller. In the first position, the motors were started with two pairs in series with the starting resistance. In the second position, all the starting resistance was cut out automatically, leaving the motors running in full series. In the third position, the two pairs of motors in multiple were connected in series with the starting resistance and the resistance was cut out automatically, leaving all the motors connected in multiple across the battery. In the fourth position, the series field of each motor was in parallel with a resistance—which further increased the speed. This sequence of operations took place simultaneously on each car and was accomplished through the train line by means of two wires running through all the cars and connected to all the motor controllers, relay panels, and polarized relays.

The trucks were of the diamond frame type and, while of light construction, proved exceptionally strong. The wheels were

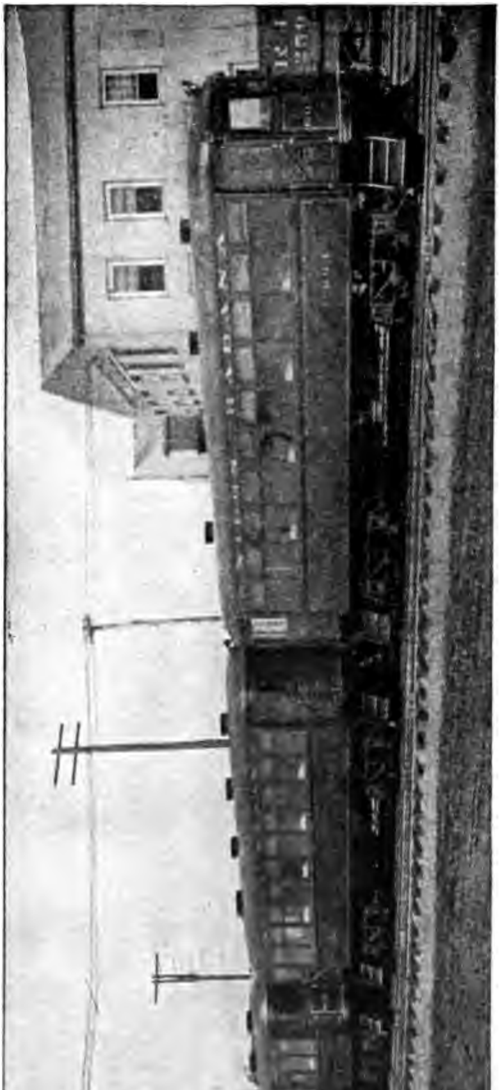


Fig. 8. Storage Battery Train Used at Havana, Cuba

steel tired, with cast-steel centers and could rotate independently of each other on the stationary axle. This was accomplished by means of a rigid axle on which was pressed a hardened nickel-steel sleeve, over which two trains of hardened rollers rotated. These rollers, in turn, were held in the hardened nickel-steel raceway, it being pressed into the wide hub of the wheel. This independent wheel arrangement was said to reduce friction, especially on curves, and to give easier running qualities.

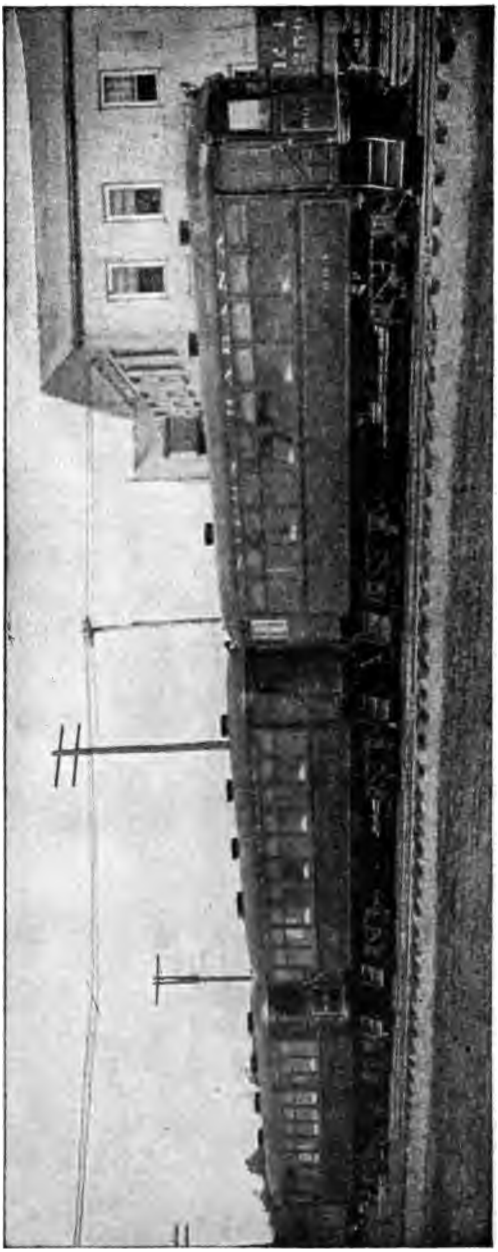
The interior finish of these cars was mahogany and polished bronze, the exterior being of cedar, while the underframing was entirely of steel construction. The cars were also equipped with M.C.B. couplers, draft rigging, and buffer plates; the platforms were full vestibuled with end doors, allowing free communication between cars. The brake equipment consisted of a powerful hand brake as well as the Westinghouse A.M.M. automatic air system, controlled from the platform of any car. An electric whistle, secured to the roof at each end of each car, could be operated by a foot button connection on each platform.

INTERNAL-COMBUSTION CARS

Gas Engine Cars Most Prominent. We will now consider the outstanding type of self-contained motor cars, namely, that in which the prime mover is an internal-combustion engine. The principal difference between the various installations lies in the type of transmission, and in treating the designs of different manufacturers, the transmission types will be especially discussed.

FRICTION DRIVE

Truck Details. One installation making use of a friction transmission is shown in Figs. 9, 10, 11, 12 and 13. This car was equipped with two internal-combustion engines of 200 horsepower each, one being located on each side of the car body, the upper part of the cylinders projecting into the car body, Fig. 11. The drive from the engine to the friction discs on the trucks, Fig. 10, was through two special universal joints. The power was delivered from a longitudinal shaft to the jackshaft by the friction discs and thence to the wheels through sprockets and chains. The wheels were loose on the axles and mounted on roller bearings, which feature was said to make the car easier riding and



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also make it take curves easier; however, the extra apparatus necessary to drive the wheels independently more than offset any

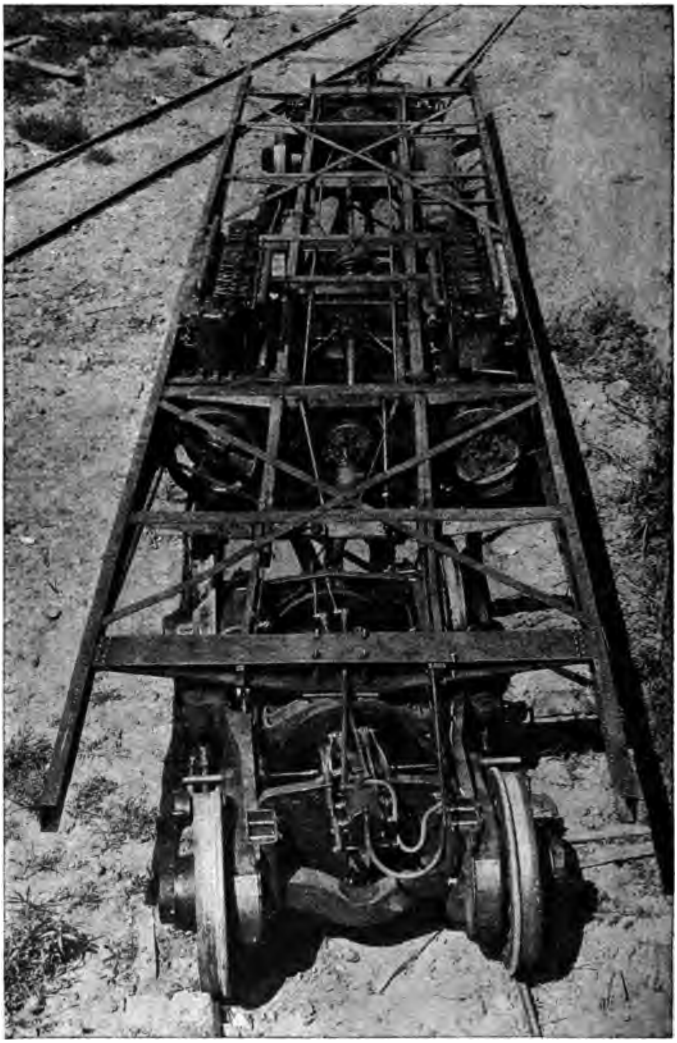

Fig. 9. View of Underframe Showing Location of Machinery

advantage gained in this way, as the frictional losses in this large amount of machinery were abnormal.

The car and equipment were so arranged that either engine or truck could be operated independently or simultaneously by

Fig. 10. Side View of Truck

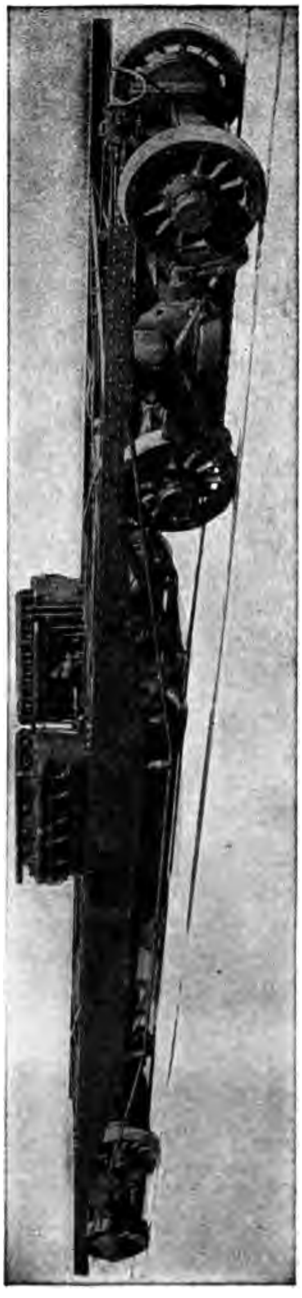

Fig. 11. Side Elevation, Showing Location of Trucks

means of an electric generator and storage battery; moreover, electric starting of the engines was provided in addition to current for the lighting system. Power for holding the friction discs

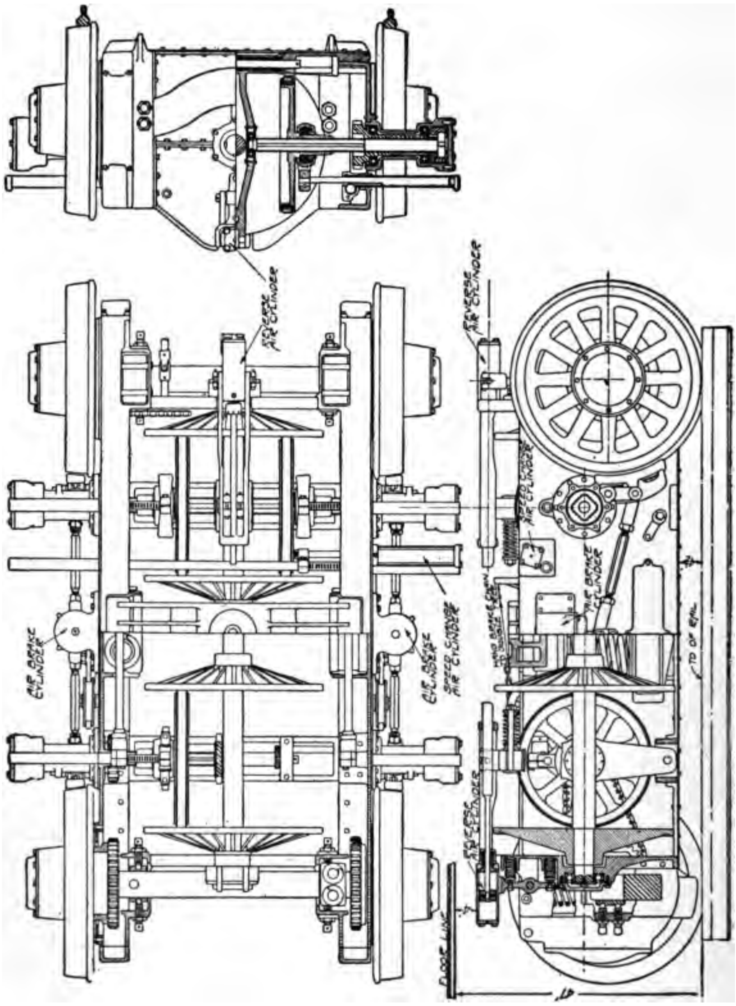

Fig. 12. General Arrangement of Friction Drive on Truck

in contact was supplied by a small air compressor direct connected to the engine. As is evident in the underframe view, Fig. 9, the air passed between the car body and the trucks through a hose, an arrangement in itself a constant source of trouble.

Control. The control system consisted of a number of levers and air valves, one set being located at each end of the car and thus providing double-end control and operation. This car was operated some ten thousand miles but was finally abandoned.

Weakness in Friction Drive. One of the characteristics of the friction drive that bears considerable investigation, especially

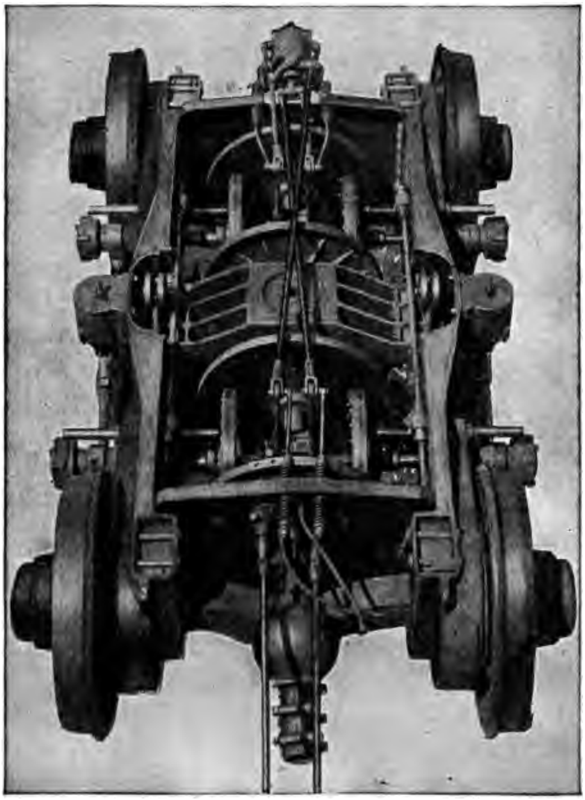

Fig. 13. Friction Drive Truck

for large units, is that the driving and driven discs must, in order to act positively, be forced together with a pressure sufficient to produce a frictional resistance equal to the maximum driving force at the point of contact, and as this so-called point of contact is in reality a very restricted area, exceedingly high unit pressures prevail between the members concerned in the transmission. It is very difficult to obtain materials of such qualities

as will give long service under these conditions of relative motion under excessive pressures.

In all forms of frictional driving, the motion of the driving and driven members one upon the other is not strictly a rolling motion but is complicated by an element of mutual slippage known as *side travel.* This produces a great waste of energy and great wear and tear on the members. Also the excessive pressures with which the members are forced together are not self-contained but produce a severe end thrust on one shaft and a heavy transverse strain on the other which only very careful engineering can successfully overcome.

For the reasons stated, it can readily be understood why the so-called friction drive is not a success for large high-powered railway motor cars. Frictional losses in this type of transmission are as high as 50 per cent.

MECHANICAL DRIVE

Orion Car. The Orion car, Fig. 14, was built by the Orion Automobile Company of Zurich, Switzerland, in 1906. Although of the single-truck type, it shows the early trend toward self-propelled cars. The body is the same as used on the Swiss railways, the front end containing the motorman's cab while the rear end is full vestibuled. All the control apparatus is in the motorman's cab. The spring suspension is of the usual single-truck type and the car is provided with couplers.

Engine. The engine and the transmission, Fig. 14, are mounted on the underframe between the axles. The engine is bolted to two cross members and depends upon the spring suspension of the car for its elasticity. It is of the Orion horizontal-opposed four-cycle two-cylinder type and delivers 30 horsepower at from 550 to 600 r.p.m., having a bore of 195 millimeters (7.68 inches) and a stroke of 205 millimeters (8.07 inches). The average speed of the car is 20 m.p.h. and it attains 25 m.p.h. on a level track. The engine cranks are set 180 degrees apart, the pistons being of forged nickel steel. All the moving parts are enclosed and lubricated by means of grease cups fed from a multiple lubricator. The gas inlet is regulated by means of a centrifugal governor.

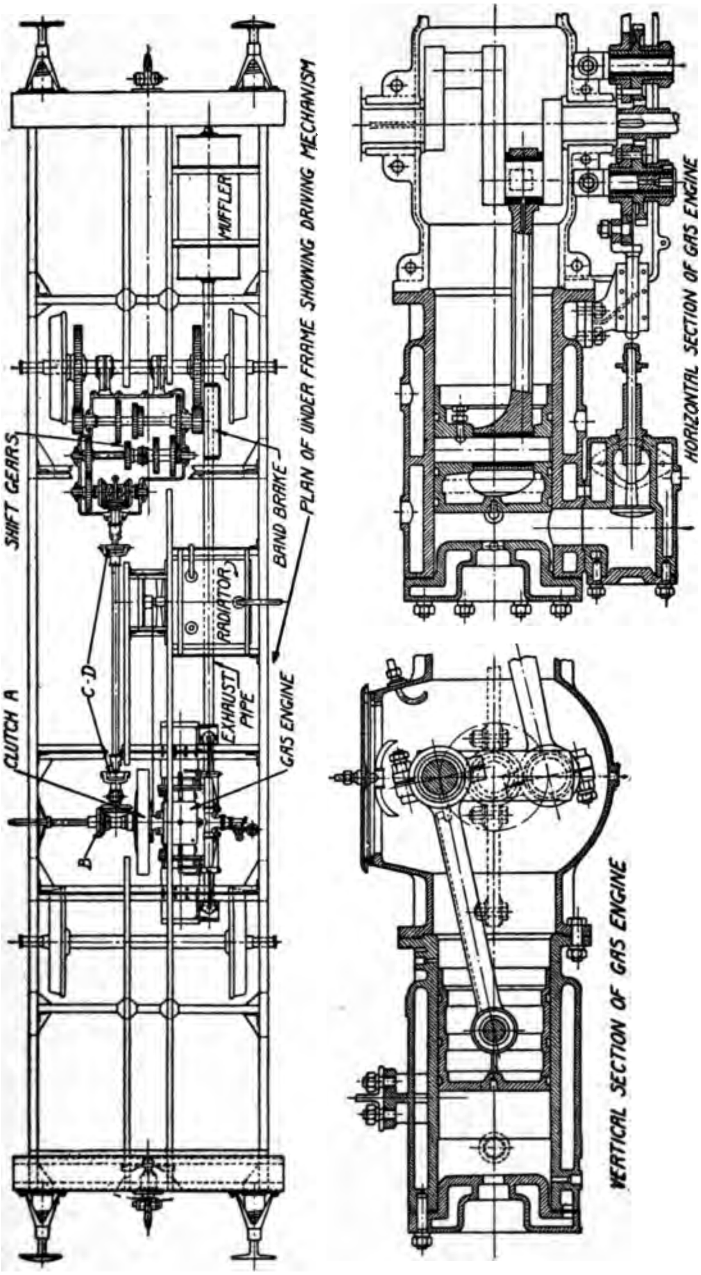

Fig. 14. Plan and Details of Orion Car

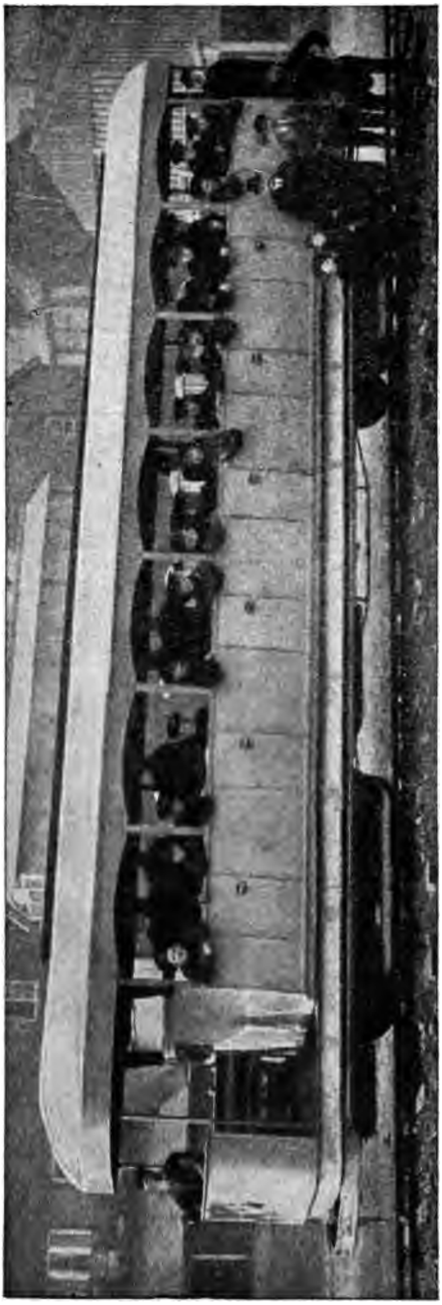

Fig. 15. Simplex Motor Rail Coach

Transmission. The transmission consists of a friction clutch *A*, and a pair of bevel gears *B*, for driving the longitudinal shaft—it having universal joints *C* and *D*. The friction clutch is set in the flywheel, which lessens the vibrations, the energy of the moving parts being transmitted in the direction of the car movement. The bevel gear is placed behind the flywheel and the power is transmitted to a second pair of bevel gears, which also serve for reversing the car movement.

The gear transmission is of the sliding-progressive type, the final drive being through a spur and pinion to the axle. In the operator's cab are the hand-brake lever, foot brake, clutch lever, and change-speed lever, only single-end control being provided. The total weight of this equipment is only 8½ tons.

Simplex Car. The Motor Rail and Tram Car Company, Ltd., of 79 Lombard Street, London, E.C., built a seventy-

passenger motor car for the South Indian Railway Company, on the Pamban Viaduct Line, which is one of the links connecting Ceylon with India. This car, Figs. 15 and 16, is of very light design, weighing only 12 tons complete, and is equipped with a 45-horsepower engine to give a speed of 25 m.p.h. on a 1 per cent grade. The car is mounted on double trucks of the swivel type which take a curve of 300-foot radius. The four-cylinder four-cycle water-cooled engine develops 45 horsepower at 1200 r.p.m. It is mounted with the crankshaft on the longitudinal center line of the car. The crankcase was especially designed for the service and has two holding-down bolts on each arm.

Transmission. The engine is connected to the transmission by an internal-cone clutch, which is kept in engagement by

Fig. 16. Underframe of Simplex Coach

laminated springs. The shaft carrying the male part of the clutch is connected through a flexible coupling to an intermediate shaft carried in a ball bearing directly behind the coupling and is suspended from a cross member of the underframe, with a similar coupling just ahead of the gear case. The gear case is mounted on two cross members of the underframe and the drive from the gear case to the worm is through a longitudinal shaft. All swiveling motion of the truck is taken up by the universal joints. This gear case is a very interesting piece of mechanism, giving three speeds in each direction, and is very small in size, though of ample strength.

The torque is taken up on double radius rods attached to the worm wheel casing and pivoted on a cross member of the frame, the thrust being absorbed by the journal boxes, these

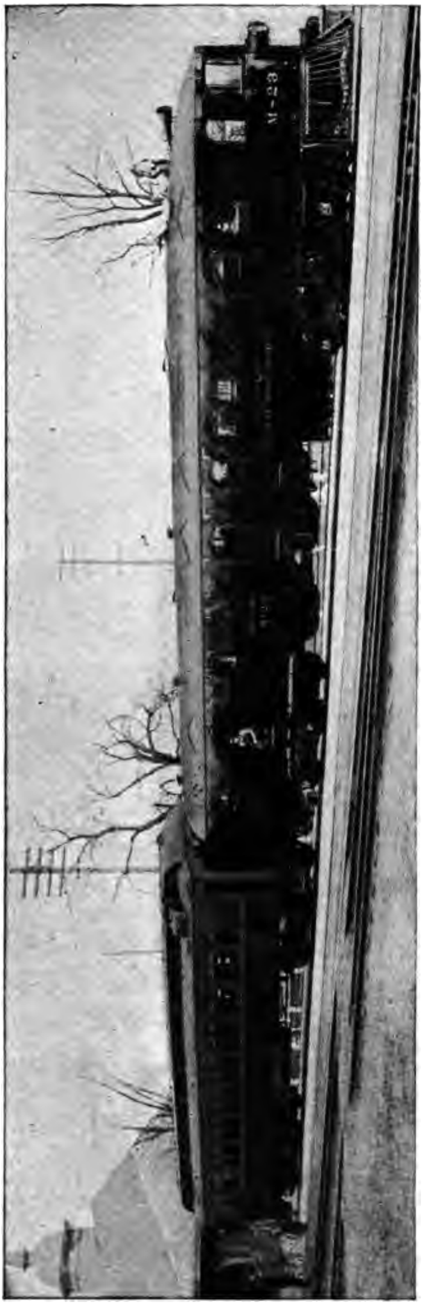

Fig. 17. All-Steel McKeen P.O.-Express-Baggage Motor Car with Coach Trailer

having been especially designed for the front truck. The gear case has three shafts, which will be designated as the engine, worm, and reverse shafts and which have their axes placed in a triangular and parallel relation to each other. The engine shaft has a single sliding spur gear on it which, if moved in one direction, meshes with a corresponding spur gear loose on the worm shaft. If this latter gear is then engaged by a jaw clutch sliding on a square section of the worm shaft, high speed in a forward direction is transmitted direct from the engine to the worm shaft. If the gear on the engine shaft is moved in the opposite direction, it meshes with a gear fixed on the reverse shaft and which gives a reverse movement to the car through another spur gear also on the reverse shaft in constant mesh with the gear previously mentioned, on the worm shaft. For the forward drive, the jaw clutch is engaged again after the gears are meshed. The sliding spur gear on

the engine shaft is thus used to convey motion from the engine to the worm shaft for either direction of car movement.

Second speed forward is obtained by the same set of gears with the addition of another spur gear fixed on the opposite end of the reverse shaft and constantly in mesh with another spur gear loose on the worm shaft. This loose gear is connected for operation by shifting the jaw clutch in the opposite direction from that required for high speed. Motion is therefore transmitted from the engine shaft through a loose pinion on the worm

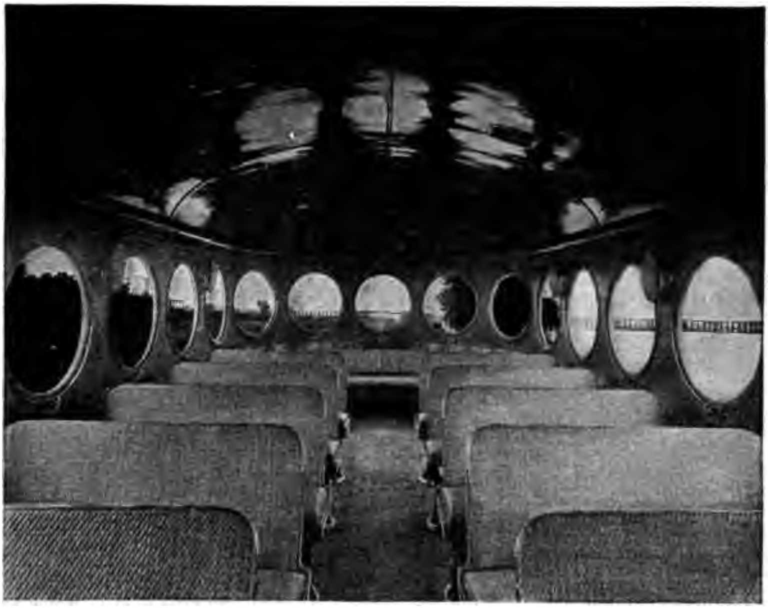

Fig. 18. Interior of McKeen Motor Car

shaft to the reverse shaft, then back through a pair of spur gears and jaw clutch to the worm shaft. It should be noted that when the car is in second speed the loose gear on the worm shaft is running at a different speed than the shaft itself.

Low speed is obtained by moving a lever carrying a jaw clutch on which is mounted a third spur gear so as to pass beyond the face of the clutch and mesh with a small pinion on the reverse shaft.

Second speed is obtained in rather a roundabout way through two pairs of spur gears, but as the low and second speeds are used only while the car is accelerating, this is not particularly

disadvantageous, seeing that the design leads to very short and stiff shafts and few parts.

Miscellaneous Details. The gasoline tank is carried about the center of the underframe. Fuel is supplied to the carburetor under pressure by a small air pump driven from the engine shaft. A water tank is placed over the engine and connected to the radiators which run longitudinally with the underframe, one on each side of the car body. The radiators are built up of fifteen 1-inch tubes running side by side and connected with a brass bend. On the platform of each car is a sector below which are three stub levers projecting above the floor and having their ends recessed in *V* grooves to engage the removable hand levers, the odd shape of the recesses preventing anyone from trying to move the levers with canes, etc. One lever is connected to the throttle, the center is for the reverse and the third lever is for gear changes, with a neutral position between each gear shift.

McKeen Motor Car. The McKeen motor car, Figs. 17 and 18, is a self-contained motor car of uncommon design using a mechanical drive and is built by the McKeen Motor Car Company, of Omaha, Nebraska. The first car appeared in 1905 and in its latest development the standard car is 55 to 70 feet in length, with end and side entrance doors. The designer has made the side of the car assist the floor beams in strengthening and stiffening the whole structure, resulting in the floor and sides being a composite girder. The location of the steps and doors is a subordinate consideration. The exterior of the car, with its pointed front end and sloping roof, gives the impression that it is suitable for high-speed service. This form of car was worked out from the Berlin-Zossen tests and is designed to overcome wind resistance to a large extent. The car is carried on double trucks, of which the front truck is the motor truck and the rear a standard four-wheel truck with 33-inch wheels. Noticeable features of this car are the round windows which are dust proof, air proof, and waterproof. Acetylene gas is used for lighting and headlights.

Engine. The motor truck, Fig. 19, has one driving axle with 42-inch wheels to which the engine power is transmitted. The engine stands on the truck and swivels with it. It is a vertical six-cylinder engine with a 10-inch bore and a 12-inch stroke in the

200-horsepower units and a 12-inch bore and a 15-inch stroke in the 300-horsepower units. The 200-horsepower engine has 4-inch valves of nickel steel and the cylinders are jacketed with $\frac{1}{8}$-inch copper.

Transmission. The crankshaft is set at right angles to the longitudinal center line of the car and is made in two pieces which carry bolted between them a sprocket wheel which by means of a 5-inch Morse silent chain connects the crankshaft and the driving axle. This axle is clutched to the driving members,

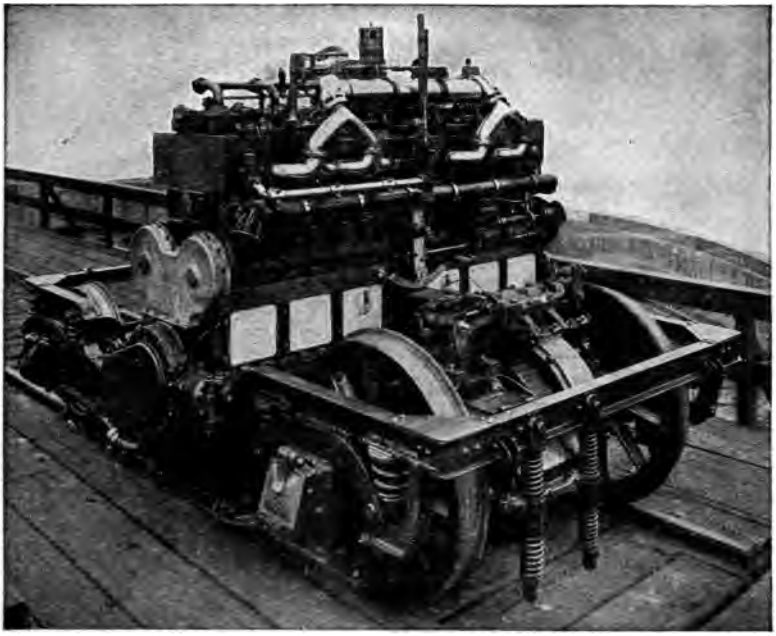

Fig. 19. Power Plant of McKeen Car

which drive either directly or through a countershaft and spur-gear reduction. Two gear ratios are thus provided and the air-operated jaw clutch throws either one or the other of these sets of gears into operation, thus obtaining a slow speed and large tractive effort or a high speed and less pulling power. In either case the variation of the car speed is obtained entirely by throttle and spark regulation. The reduction gears are carried on the axle. With the low-speed gearing the full engine power is ordinarily obtained at about 10 to 15 m.p.h., while with the high gear,

or direct drive, the full engine power is obtained at the maximum running speed of the car.

The control is entirely pneumatic and consists of several small levers governing the two-speed and reversing mechanism. The gears run constantly in mesh and are clutched in with special jaw clutches. Two of the levers control the carburetor and the ignition.

Air Compressors. The engine is reversible, having sliding camshafts, and can be started in either direction by means of compressed air supplied from the brake reservoirs. These are kept charged by a small air compressor direct connected to the engine crankshaft. A separate air compressor, which is driven by a single-cylinder four-cycle gasoline engine, is installed in the

Fig. 20. Hall-Scott Motor Car

engine room to provide air in case the air for starting is low, and for emergency use. The auxiliary compressor is of McKeen design and is so constructed that the piston of its gasoline engine does double duty. Not only is it the piston of the engine but also the compressor of the air on the down stroke. The same air is used for operating the brakes. An auxiliary valve motion on two of the main engine cylinders converts these cylinders into an air motor for starting, after which the engine again operates as a complete gas engine.

Circulation. The cooling water is piped to the radiators, which are carried beneath the car body and are well protected from flying stones. In cold weather the water goes to the heating coils inside the car and furnishes adequate heat. In

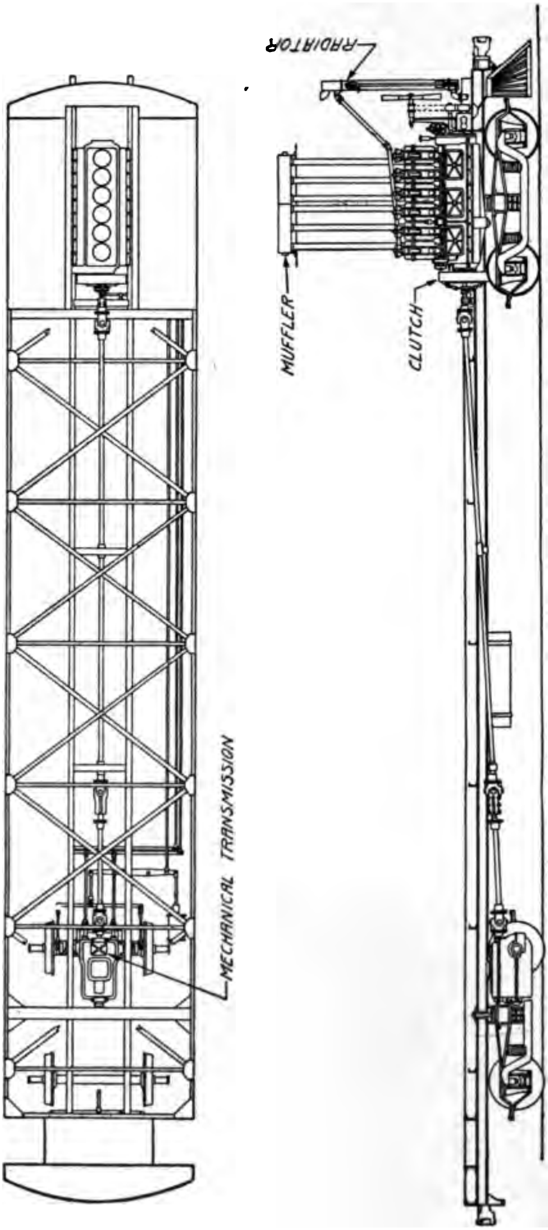

Fig. 21. Power Plant of Hall-Scott Motor Car

exceptionally cold weather the exhaust pipe may be used, in addition, if necessary.

Hall-Scott Car. *Drive Shaft.* The Hall-Scott car, Fig. 20, like the McKeen, is mechanically driven, with the difference that the engine is mounted in the front end of the car and is connected to the driving wheels on the rear truck by universal joints and a long drive shaft, through a gear case, Fig. 21. The drive is patterned after automobile practice. The first section of the long drive shaft is suspended between two 7-inch I-beams running the entire length of the car. It is supported in babbitted bearings which, in turn, are bolted to the I-beams. The second part of the shaft is supplied with universal joints at each end to take care of the vertical and lateral motion of the truck. The shafting and universal joints are of extra heavy construction.

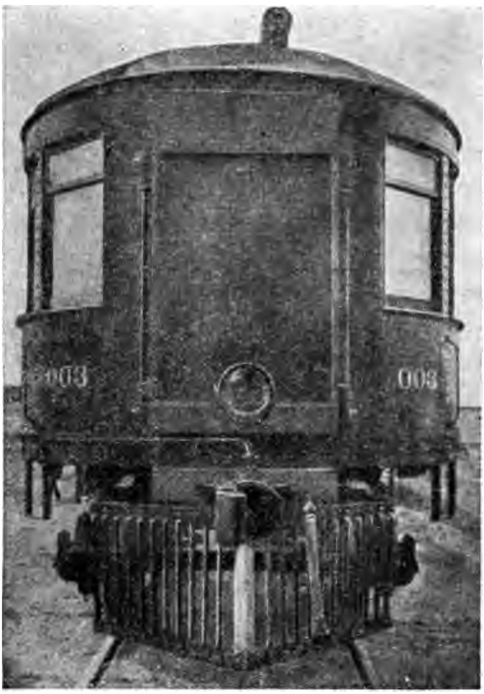

Fig. 22. Front View of Hall-Scott Motor Car, Showing Radiator Position

Connection between the engine and the drive shafting is by means of a split steel band clutch, which is lined with a nonburn material, is located in the engine room, and is actuated by a steel foot lever. The clutch is arranged to release completely without drag and a positive lock is made when it is thrown in the holding position.

Transmission. The power is transmitted to the wheels through an axle-mounted transmission arranged for four selective speeds in either direction without reversing the engine. The transmission is built up of three steel casings securely bolted

and permits easy access to the driving gears. It is suspended from the rear truck axle in the same manner as an electric motor, with journal boxes cast integral with the steel casing and having removable journal brasses. The third point of the nose suspension rests on a hardened steel plate on the truck transom. The spur and bevel gears are machined from high-carbon cast steel and steel forgings, are heat treated, and are supported on roller bearings. All gears run in an oil bath in the case, which is oil and dust proof.

Fig. 23. Six-cylinder, 150-hp. Engine Installation in Hall-Scott Motor Car

Circulation. In the 150-horsepower motor car, the radiators are carried on the front end of the car, Fig. 22. They are of the vertical tube type, are suspended on shock-absorbing springs, and have a large cooling fan direct driven from the engine. Circulation is by a centrifugal pump, but the radiator position also allows thermo-siphon circulation, if required.

Control. The control levers are all located in the engine room, Fig. 23, the four speeds allowing for large flexibility of control for handling switching, hauling trailers over grades, and doing other heavy work. At the same time a high-gear ratio is provided so that the car may be operated at high speed on level tangent track.

New Era Car. The New Era motor car designed for the Railway Contracting and Equipment Company of Chicago is radically different from the usual gasoline mechanical-drive cars in that each truck contains a complete power plant so arranged that any number of cars in a train provided with motor trucks may be simultaneously controlled and operated through a train line by a single operator from any car. These trucks, Fig. 24, may be arranged to be applied to any car and consist of an all-steel standard M.C.B. truck with a 6-foot 6-inch wheel base and a four-cylinder four-cycle V type gasoline engine, having a $6\frac{3}{4}$-inch cylinder bore and a $7\frac{3}{4}$-inch stroke and being capable of developing 120 horsepower at 1000 r.p.m. All the mechanism is readily accessible by removing the cover plates and may be inspected from the car body by removing the trap doors.

Engine. Special attention had to be given to the design of the engine and the transmission, Figs. 25 and 26, in order to place them within the space available in a standard truck with the above wheel base and to provide accessibility and ample proportions. No part of the engine or the transmission projects above the wheel tread. The crankshaft, Fig. 25, is of ample size and is mounted on extra large self-aligning ball bearings in order to keep the over-all length of the engine within the prescribed limits. The camshaft is extra heavy and projects at the rear to drive a two-cylinder air-cooled air compressor having a $4\frac{1}{2}$-inch bore and a $3\frac{1}{2}$-inch stroke and furnishing 30 cubic feet of air per minute at 90 pounds gage pressure. The valves are of tungsten steel and are actuated by means of rocker arms. Starting is by means of a 30-volt electric motor and is controlled by the master control lever. Atwater Kent automatic-advance ignition and water and oil pumps are located conveniently for adjustment and cleaning. The exhaust is piped to two mufflers directly beneath the engine, one muffler for each two cylinders. The carburetor is of the float-feed type and is located as close as possible to the inlet valves. Forced and splash lubrication are employed.

Transmission. The drive shaft is coupled direct to the engine shaft, the coupling being shown at the right in Fig. 27. It drives a jackshaft through a pair of bevel gears, which are arranged so that, by means of a steel four-jawed clutch, Fig. 25,

the jackshaft may be driven in either direction, thus providing means for reversing the car direction without reversing the engine. From the jackshaft a drive is taken off from each end; at one end the gear ratio is 5 to 1 and at the other it is 1 to 1, except in locomotive equipment when the final ratio is 2.4 to 1. Individual single dry disc clutches are used on the drives and are operated electro-pneumatically.

Both pairs of wheels are driven, since they drive each other by means of bevel gears on each axle, and they are connected together through a shaft and a universal joint to permit lateral and vertical movement. The transmission gears throughout are either spiral cut bevels or herringbone. All gears and clutches are thoroughly encased in oil-proof and dust-proof casings.

The transmission casing together with the engine and the air compressor are carried on a three-point suspension. By means of its two bearings on the axle the transmission casing at one end forms two points of the suspension, while the longitudinal members, which support the engine and the air compressor, are connected together at the rear end of the truck and form at this point the third point of the suspension. This suspension method relieves the engine and mechanism from all strains due to vertical and lateral motion of the truck frame.

Light, Fuel, and Circulation. A drive shaft is taken from the bevel drive on the rear axle of each truck, and the axle lighting generator is driven by this shaft and a universal joint. It may be driven from either truck, according to which truck is at the generator end of the car. This generator charges a 300-ampere-hour storage battery, which is used for lighting the car and operating the control circuits. Fuel is supplied to the carburetor through a $\frac{3}{8}$-inch locomotive-type swing joint. Pipes on the car body conduct the cooling water to the radiators by means of swing joints of the same kind as on the carburetor but of a larger size.

Control. The control system is electro-pneumatic and is operated from the current of the storage battery. A train line of twelve wires is provided and is fitted with a jumper, so that any number of motor cars may be coupled in a train and operated simultaneously. A small master controller in the cab of the car or locomotive is the only lever needed for complete operation. Only

one lever is used, but it includes an auxiliary lever for speed changes. The carburetor is controlled through the variation of the speed of a small 30-volt electric motor driving a small governor which is balanced and operates against a graduated spring; thus any number of carburetors may, after being set, be caused to open simultaneously and in unison. The clutches are provided with electrically operated air valves and are graduated for a given rate of acceleration.

Operation. Operation of the car is as follows: Placing the controller handle on the first notch cuts in the electric starting motor and the ignition; advancing the controller handle to any other notch speeds up the engine accordingly by opening the butterfly valve. On the end of the controller handle is a button, which may be depressed to two positions. Depressing this button to the first position operates the electromagnet that admits air to the low-speed clutch, and this, in turn, clutches in the low-speed gears. This electromagnet air valve, as before stated, is graduated to admit air to the clutch-operating mechanism at a rate corresponding to a given rate of acceleration. Depressing the button to its farther position both breaks the circuit of this electromagnet, which instantly releases the low-speed clutch, and at the same time connects in the electromagnet which operates the high-speed clutch—and which is graduated like the other for a given rate of acceleration. An engineer rapidly learns when to depress this button for change-speed gears, and even if he does not always do it at the same time, no harm can result and the engagement of the clutches takes place correctly.

On releasing the button, the reverse action takes place and the low gear may be dropped in again or the transmission entirely released. Also, reversing the movement of the controller handle slows the engine down or shuts it off entirely. Any combination of engine speed and gear ratios may be had through the operation of this handle and button. To reverse the direction of car travel, a small lever on the master controller case is moved, which operates the reversing clutch on the jackshaft through an electromagnet-operated air cylinder.

Either or both engines under a car may be operated, and if one is operating, the other may be cut in at any time.

ELECTRIC DRIVE

Foreign Cars

Drake Automotrice. The gasoline-electric car may be briefly described as an interurban trolley car with the trolley removed

Fig. 28. Gasoline-Electric Automotrice "Dracar"

and a power plant—consisting of an electric generator direct-connected to and driven by a multiple-cylinder gasoline engine—installed in the forward part of the car. The fundamental difference between the gas-mechanical drive cars and the gas-electric cars is that in the latter the engine drives an electric generator and power is transmitted electrically to the motors geared to the axles instead of the other method—that of the engine being direct-connected by mechanical gearing to the axles. The Drake Automotrice, Figs. 28 and 29, is taken as representative of the gas-electric type. Some of these cars have been built in the United States and put in operation on the Missouri, Oklahoma, and Gulf Railway, while their most extensive use is on the Arad-Csanád Railway in Hungary, which service began in 1905. The generator is a 500-volt machine and the energy is conducted from the power group to the control system, comprising series-parallel connections of the motors, Fig. 30, with field regulation

Fig. 29. Front End of Automotrice, Showing Power Group

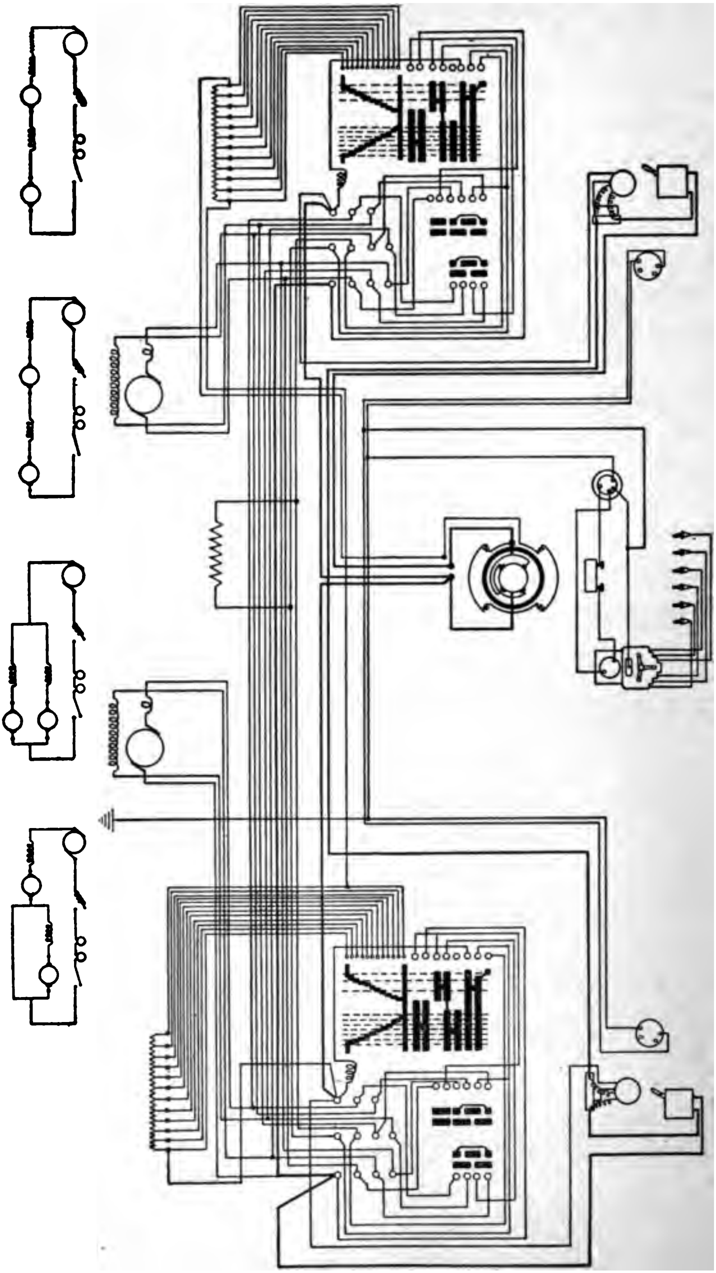

Fig. 30. Control System of Automotrice

and a variable carburetor control, or throttle. The series-parallel control is essentially the same as that used in electric interurban service. The contactors are arranged for ten steps of field resistance, which are incorporated in the series-parallel sections of the controller.

Engine. The engine is designed for speeds of from 900 to 1000 r.p.m. and is built in two sizes, 90 and 140 horsepower. The control levers are arranged to open and close the gas admission to the engine mechanically and for wide variations of acceleration and speeds. The car is provided with duplicate controllers permitting operation from either end of the car. The motors are mounted on the forward trucks, as is the usual practice, and are of the standard interurban type.

The engine jackets are supplied with cooling water circulated by a positive-driven geared pump, propelled by the camshaft. The cooling is by a copper tube radiator placed on the roof of the car. In winter this cooling water is used for heating purposes. The engine is started by cranking, just as in an automobile, the compression being relieved momentarily during starting.

Pieper System. The Pieper system (French), Figs. 31 and 32, consists of an internal-combustion engine corresponding to the power to be developed; a generator which is

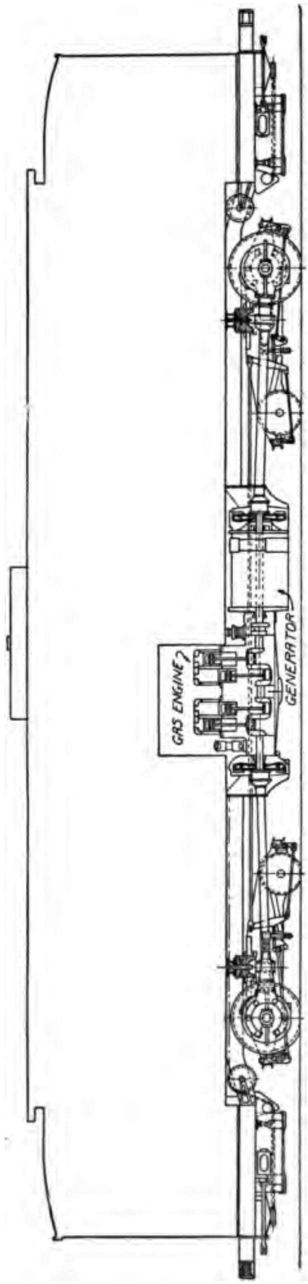

Fig. 31. Diagram of Running Gear of Pieper Car

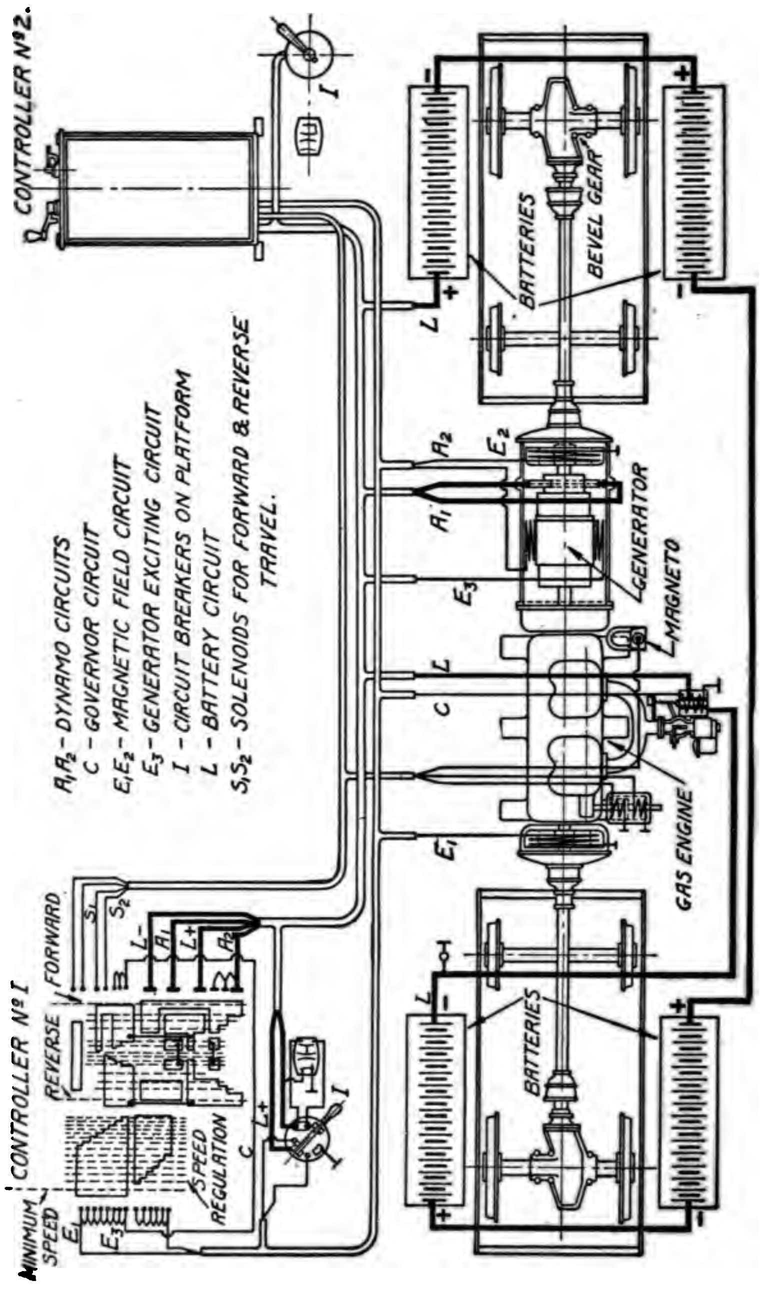

Fig. 32. Wiring Diagram and Power Plant of Pieper Car

mounted direct on the shaft of the flywheel of the engine and which functions either as a generator or a motor at different speeds by regulation of the excitation; and a storage battery.

Storage Battery. The storage battery furnishes additional energy for the generator when the engine is insufficient and is recharged from the generator when excess power is generated in slowing down or descending a grade. This double action is obtained in the following manner: when the car is on an up grade, the engine is consequently slowed down and the voltage of the generator drops below that of the battery, which causes the current to flow from the battery to the generator, an operation called the "buffer"; similarly, on a down grade, the engine speed is accelerated and the generator voltage rises above the battery voltage, thereby recharging the battery. The "buffer" and the recharge occur automatically. The work of the battery in the Pieper cars is essentially different from that of batteries in ordinary traction service. In other words, in traction cars the batteries are required to furnish all the energy necessary to pull the train, which means a constant drain at almost full capacity, while in the Pieper system "buffer" battery furnishes only a part of the energy. Consequently, the Pieper battery need not be of large capacity and requires only a little space. This does away with the inconvenient weight of the ordinary batteries. The battery used in this system should not be larger than necessary, as the principle of the system consists in having the engine itself furnish the average power required.

Regulator. The admission of gas to the engine is controlled through a regulator, which consists of a double-wound solenoid with a soft-iron core and which actuates the butterfly valve of the carburetor. This regulator increases or diminishes the flow of the gases following the flow of the charging or discharging current of the battery in such a manner that, for example, when on a grade —in which case the engine requires more fuel—the regulator opens the throttle and when on a down grade, the regulator automatically closes the valve, thus giving gas to the engine only as required.

Control. The car can be operated from either platform by a controller similar to those used on the ordinary electric trolley car. A small handle serves to start the engine, forward or reverse, by

the generator acting as a motor. After the engine is set going, the operator moves the large controller around, this giving a progressive flow of current to the magnetic fields of the motors and starting the car. The speed is then increased by progressive elimination of the resistance inserted in the field circuit of the generator. When slowing down or stopping, the large controller handle is moved in the opposite direction and the excitation of the generator is gradually increased, charging the battery through the inertia effect of the car. When the handle is on the zero position, the transmission is neutral, and when moved farther, it finally actuates a magnetic or an air brake as the case may be. This brake serves to block the wheels only during the time of full stop, as the slowing down braking is accomplished by the process of recharging the battery. In consequence, the use of the brake shoes is minimized.

In the operation of the car, the "buffer," the recharge, the admission of gas, driving the car, and speed regulation are automatic; all the operator has to do is to maintain the speed of the car through the controller and finally recharge the battery.

Miscellaneous Details. Heat is obtained by means of the circulating water from the engine and can easily be regulated to the proper temperature. The motor car and the trailing coaches are lighted by means of incandescent lamps, current from the buttery circuit being used. Double-truck cars weigh from 20 to 22 tons, are equipped with a four-cylinder 90-horsepower engine and a battery of sixty elements weighing about 1800 kilograms (3960 pounds), and have a seating capacity of twenty-five to thirty. A speed of 50 m.p.h. on level tangent track has been obtained. A larger equipment has a six-cylinder 150-horsepower engine and two generators with 120 elements in the battery and is capable of pulling two trailers. These cars were in service on the Belgian State Railways and the de Saint-Germain à Poissy line. This car is similar to the Strang described on page 59, though it is now obsolete owing to the fact that the generator current and voltage may be regulated in such a manner as to produce regulation of the kind here described without the use of a storage battery.

German Cars. The Prussian State Railways were among the first to use self-contained railway motor cars. Starting with steam cars, they later used storage batteries and finally adopted

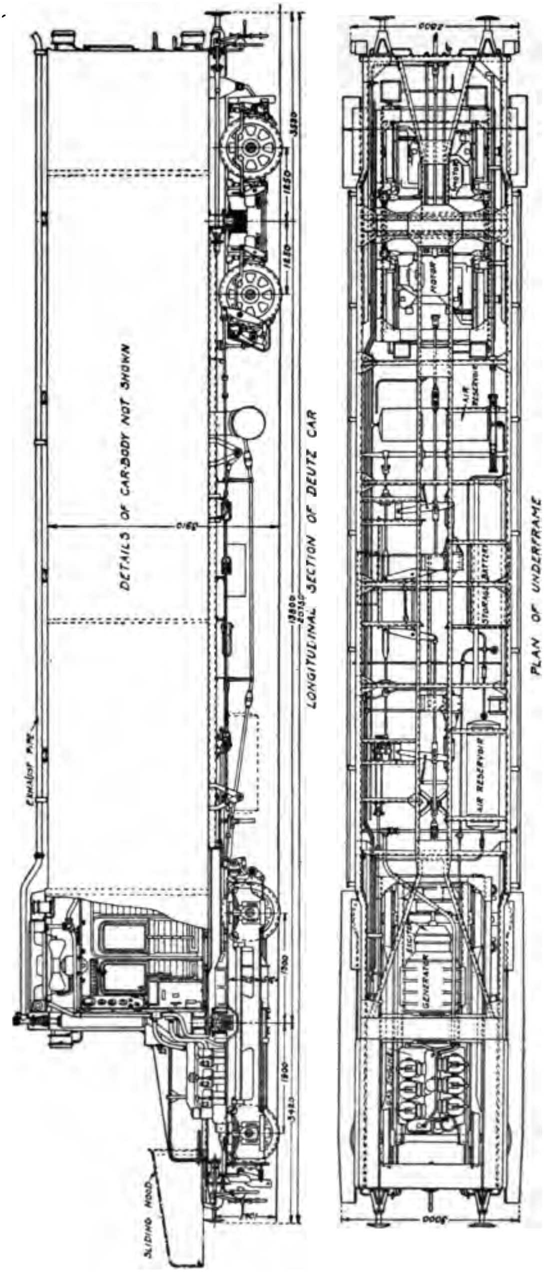

Fig. 33. Plan and Longitudinal Section of Underframe of Deutz Car

the gas motor. The steam car presented so many difficulties and drawbacks that continual experiment was necessary and no satisfactory service obtained. Storage batteries proved satisfactory with regard to simplicity in operation and cleanliness but increased the cost of operation, as did the necessary charging stations. These facts, together with the great weight of the batteries, limited the radius of operation. In the five years from 1908 to 1913 the Prussian State Railways installed gas-electric cars with Ward-Leonard control. This control permits changes of the current through a shunt generator by changing the exciting field, thus using the maximum engine power as needed. This regulation of the cur-

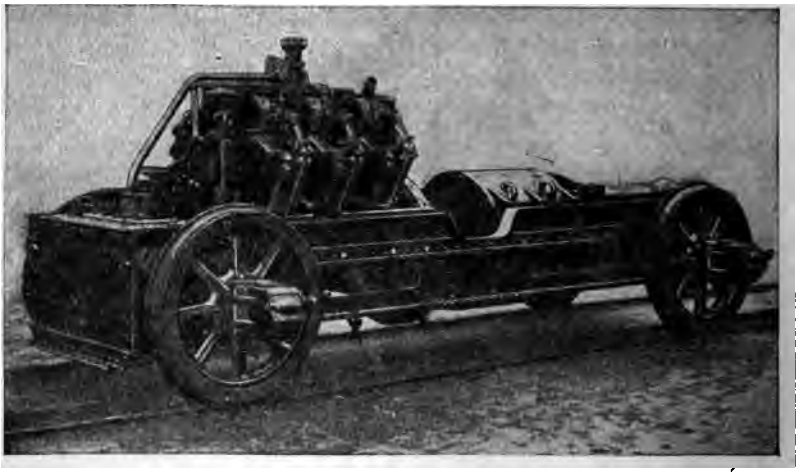

Fig. 34. Gas-Electric Power Plant for Deutz Car

rent for speed changes is very easy, whereas the storage battery control is more complicated, owing to the extra heavy flow of current.

General Data. Following is a description of the system on the Bentschen-Posen section of the Berlin-Posen Railroad, which has been in operation since the middle of 1911. The cars were furnished by the Gasmotoren Fabrick Deutz (G.F.D.), the Allgemeine Elektrizitäts Gesellschaft (A.E.G.), and the Neuen Automobil Gesellschaft (N.A.G.).

The latest Prussian Railway gas-electric motor cars, Fig. 33, have all the machinery outside the car body and under the operator's cab, which eliminates a number of difficulties encountered

with the usual methods. The gas engine and accessories, including the gas tank, are placed entirely on the truck and under a hood which can be slid forward easily; the exhaust fumes are led out toward the roof; and the whole car body can be insulated so as to be fire and odor proof. The vibration of the engine and the machinery is minimized through the spring suspension of the truck; and since the power plant is outside the car, greater utilization of the interior of the car is possible.

The engine is equipped with an air starter fed from the brake reservoirs, the air compressor being driven by the gas engine. To

Fig. 35. Gas-Electric Power Plant on N.A.G. Car

reduce the engine vibration while coasting or at a stop, the engine speed, which is automatically controlled through the controller lever, is brought down from 700 to 250 r.p.m. This effects a considerable saving in fuel, taking into account slow downs and stops. The rigid wheel base of the trucks depends upon the type of engine. The G.F.D., Fig. 34, is an early type V engine with six cylinders, which on account of its minimum length permits a wheel base of 3.8 meters (12 feet 5.61 inches), and a symmetrical arrangement of the truck. The N.A.G. engine, however, is a four cylinder vertical type, Figs. 35, 36, and 37, which increases the wheel base to 4.25 meters (13 feet 11.32 inches), and causes

the bolster to be set off center 255 millimeters (10.04 inches). Observations showed little difference in these types while traveling

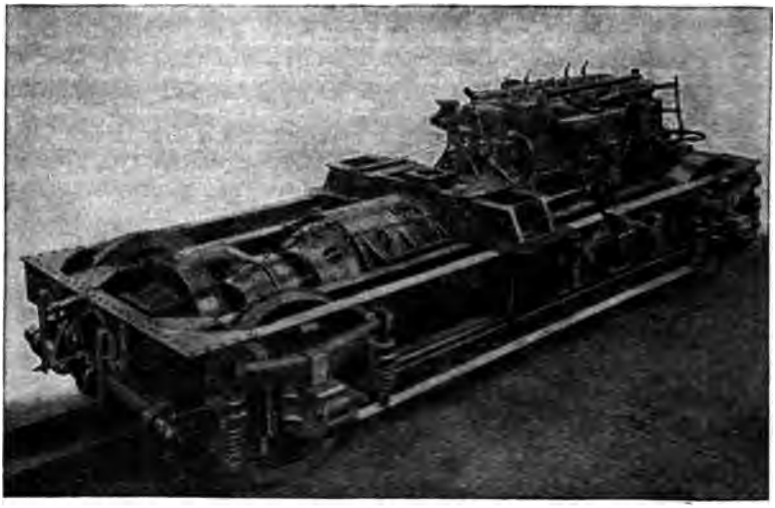

Fig. 36. Power Plant on N.A.G. Car, Showing Location of Generator

at high speed, but the uniformity of the speed of the six-cylinder engine should not be overlooked, especially at low engine speeds.

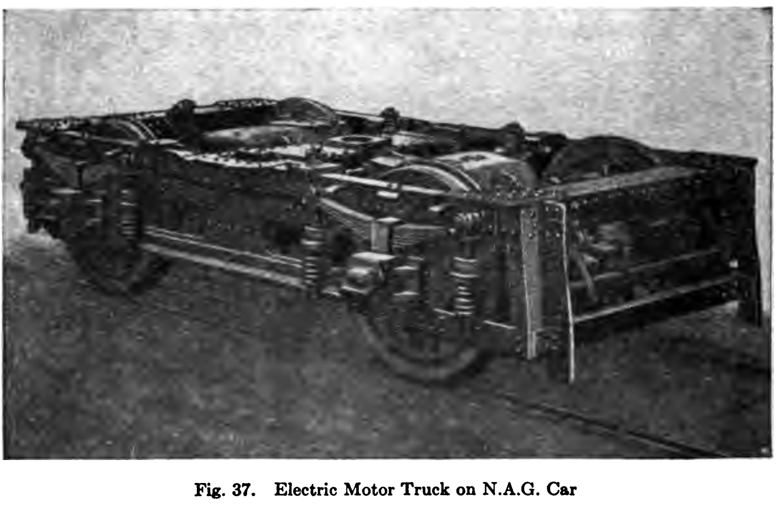

Fig. 37. Electric Motor Truck on N.A.G. Car

G.F.D. Engine. The G.F.D. engine is rated at 100 horsepower at 700 r.p.m. and can develop 150 horsepower without

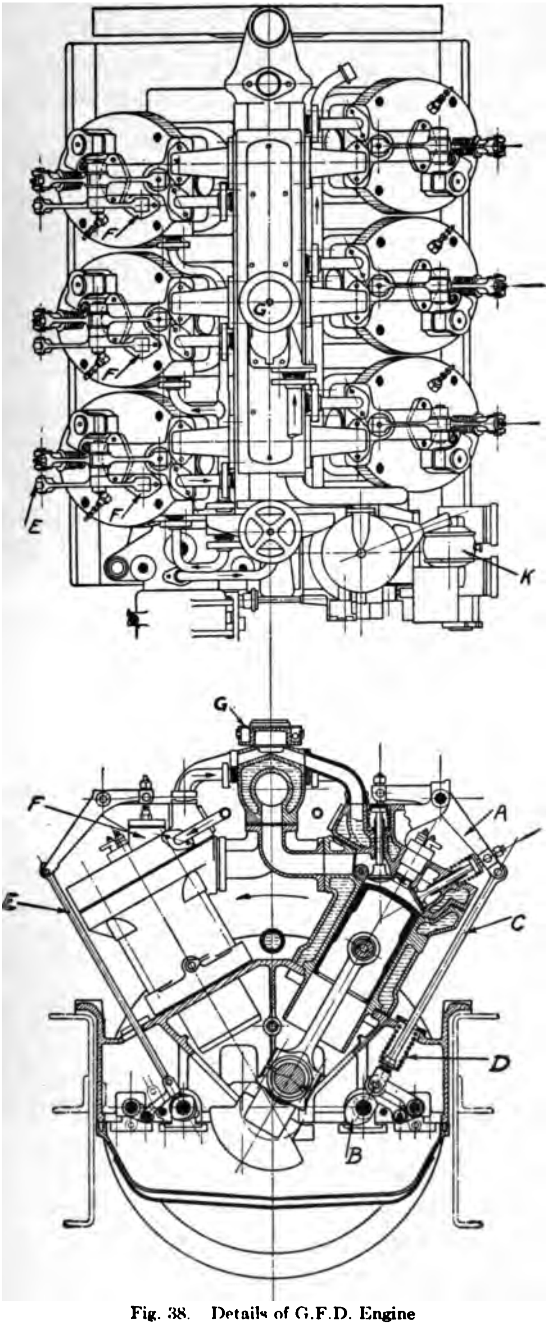

Fig. 38. Details of G.F.D. Engine

difficulty. The cylinders have separate bolted-on valve caps, Fig. 38, and the valves are inclined uniformly toward the cylinder axis, thus forming a ball-shaped compression chamber. The cylinders are inclined at a 60-degree angle and are bolted on in two rows to the upper part of the crankcase. The lower part of the crankcase is bolted on and is removable for inspection of the connecting rods and crankshaft bearings. The three throws of the crankshaft are 180 degrees apart and each throw takes two connecting rods, the crankshaft having four bearings.

Both valves of each cylinder are actuated through a common bell crank *A* by means of the cams *B*. The push rods *C* are pulled toward the camshaft by the spring *D* to open the intake valve and pushed outward by the cams to open the exhaust valves. The cylinders of one side of the engine are provided with an auxiliary cam set, which controls the air governor, consisting of an air compressor valve *F*, actuated through a special rod *E*, that opens once for each revolution of the engine. To the crank rod operating this rod, Fig. 38, is connected an attachment for varying the density of the mixture on the other side of the engine. When started by air, the gas engine really is two machines running simultaneously, one side as a two-cycle air motor and the other side as a four-cycle gas engine; whereas, in general practice, the fuel is admitted to the engine only after the air auxiliary is shut off. This method increases the certainty of the explosions. To guard against exceeding the correct revolutions per minute, a governor is fitted to the vertical shaft, it being driven from the end of the camshaft and controlling the throttle valve on the carburetor. An eccentric pin on the large governor crank is, after changing from light to tractive load, so operated by an electric motor *K* that the previous position of the governor causes an increased opening of the throttle valve. In this way the engine increases its speed to 700 r.p.m. before it can pick up any more load.

The location of the other equipment is governed by the desire to utilize the space to the best advantage and, therefore, the exhaust and the intake pipes are set between the cylinders where they are joined in a cooling housing. This arrangement brings about a simultaneous cooling of the exhaust gases and a pre-

heating of the fuel gas. A water-circulating pump and a high-tension magneto are located on each side of the vertical shaft. The magnetos are used only in case of an emergency, the current for the spark being taken from the storage battery, which also supplies current for other uses. The air compressor is mounted on the front end of the camshaft and feeds two reservoirs of 400 liters each ($14\frac{1}{8}$ cubic feet) at a pressure of about 90 pounds per square inch.

A high-pressure pump forces oil to all bearings, while the cylinder walls are lubricated by separate grease cups. The exhaust and cooling pipes are connected to the car body through flexible joints and lead to the roof. Moreover, the cooling pipes may be connected to the heating coils in the car by the proper operation of valves. An electric fan sucks the air through the radiators and forces it out again, the fan being independent of the car speed. The remaining space is used for a gas tank, in which the fuel is kept under the protection of some neutral gas to prevent explosion. The gas is supplied from a steel tank through a low-pressure valve, which is arranged so that the fuel can flow out only at the top and at the proper mixture.

N.A.G. Engine. The N.A.G. engine, Figs. 35, 36, and 39, differs from the G.F.D. engine in the arrangement of the cylinders and some of the minor details. It has four cylinders in a row, each of 196 millimeters (7.72 inches) diameter and 250 millimeters (9.84 inches) stroke; possesses a large ratio (1.325 as against 1.06 in the G.F.D. engine); and will develop 120 to 125 horsepower at 700 r.p.m. The construction of the engine is along the same lines as that of the Deutz. The cylinders are cast in pairs; have interchangeable valves; are of the T-head type, which gives the engine a neat and simple appearance; and are mounted on the upper half of the crankcase, which is bolted to the truck frame. The crankshaft bearings are also mounted in the upper half of the crankcase; the lower half, which is used for an oil reservoir, is made of aluminum and is demountable.

The power for driving the various appliances of the N.A.G. engine is taken from the front end, the speed regulator being arranged similarly to that of the G.F.D. engine and being electrically controlled. The water pump and the high-tension magneto

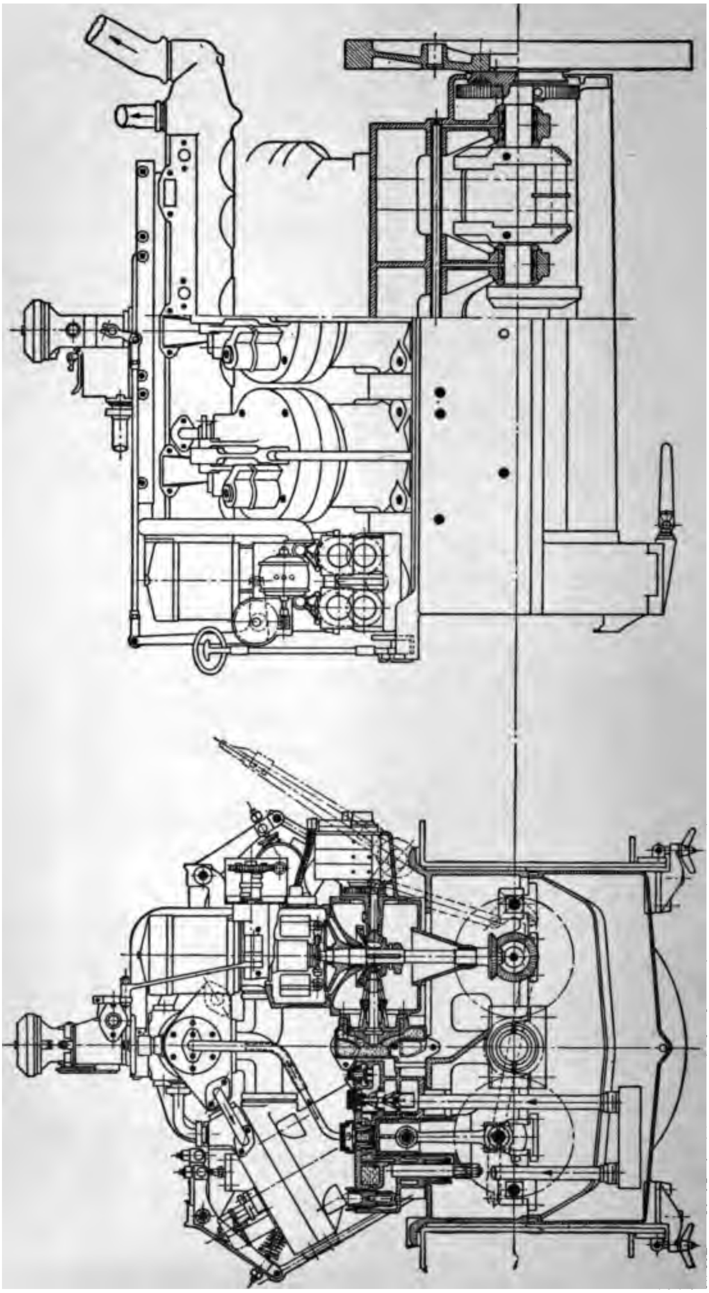

Fig. 29. Details of Magneto and Water Pump on N.A.G. Engine

are operated from the lower end of the regulator shaft, Fig. 39, while the air compressor is driven from the opposite camshaft. Ordinarily, the engine is started by air, and for this purpose there is a housing *A*, Fig. 40, over the center of the camshaft in which are mounted four inlet, or distributing, valves *B*. Two cams actuate two levers *C* shaped like an L, and through the upper end of which runs the shaft *D*, which lifts the levers off the cams as soon as the engine starts to run, whereby the influx of air is automatically cut off. As a rule, the engine has to be stopped at a certain place in order to start properly, and unless this is done, it has to be turned over by hand. The air flows through the

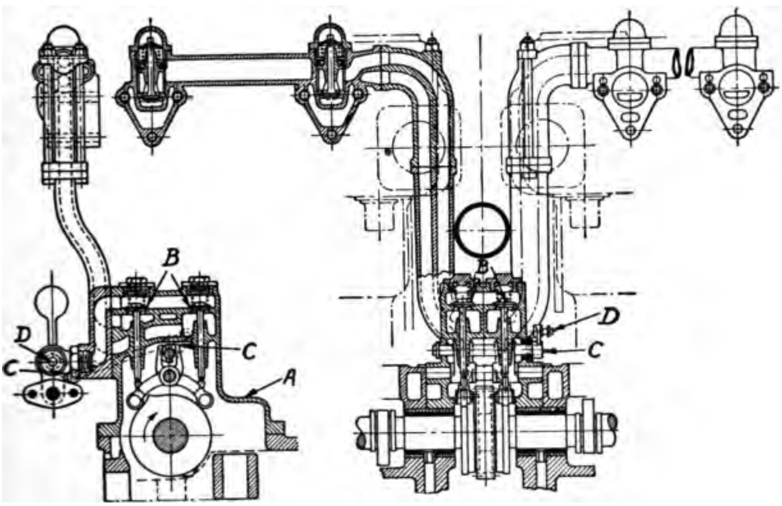

Fig. 40. Details of Valves for Starting N.A.G. Engine by Compressed Air

carburetor until the explosions take place and then it is automatically cut off.

Fuel. Both the N.A.G. and the G.F.D. engines run on benzol, which is advantageous owing to its low imflammability. The danger of its freezing if the temperature is below zero is done away with by means of a heating encasement, while for emergency a certain amount of gasoline is carried, principally to start the engine in cold weather. Sufficient fuel is carried for 200 miles, which means that the tank has to be filled only once daily.

Electrical Equipment. The electrical equipment is similar on both the N.A.G. and the G.F.D. cars, each having the engine

direct connected to shunt generators which develop 66 kilowatts, 300 volts at 700 r.p.m. and which can be loaded for 30 hours with 530 amperes. The generators are enclosed and provided with a ventilated armature which is built into the trucks and connected to 2.5 kilowatt exciters of 70 volts, in the circuit of which is cut the necessary resistance for regulating the voltage and the amperage of the generators.

In the control of the car equipped with the A.E.G. engine, Fig. 41, there are three circuits. The main circuit connects the main generator *A* to the main generator field *Y*, the magnetic coil of the full-load release *K*, the overload contact *L*, and the two permanently connected and grounded car motors *H*. In the exciting circuit is included the exciter generator *C*, the shunt winding *B* of the main generator, and the starting resistances *M* in the controller. The auxiliary circuit includes a storage battery *X* of 20 cells with a 74-ampere rating, the full-load release contactor *K*, the magnetic coil of the overload relay *L*, and the push button *N* of the controller.

The battery serves to supply current for lighting and other needs of the car while standing or at very low speeds. It is grounded at one end and the other end is connected through the release contactor *T* with the positive terminal of the exciter. As the negative terminal of the exciter is also grounded, the discharging circuit is closed as soon as the voltage of the exciter is high enough to close the release contactor, which occurs as soon as the engine develops a speed of 700 r.p.m. The exciter then charges the battery and supplies current for other needs.

Control. During forward travel, the operator puts the shunt connector button *N* of the controller in the proper position by means of the controller handle and thus obtains the necessary connection to the motors for the required speed. At the same time the controller which controls the overload and signal circuits is put on "trip." By pushing the button *N*, the battery circuit closes the magnetic brake coil. By moving the controller handle to the first position, the contactor *L* is closed, and at the other positions a resistance coil is cut into the contactor circuit. In the first position of the controller handle the battery starts the auxiliary motor on the engine regulator, Fig. 41, and the engine

speeds up to 700 r.p.m. The teeth on the worm gear are so cut that, at the proper shaft speed, the motor drive is automatically cut out.

With the increase in speed of the engine, the exciter reaches its full voltage. In the first position the whole resistance is cut in on the field of the generator, which allows the motors to run at low voltage but high ampere load, thus giving the greatest pull. In the generator *A*, Fig. 41, current flows through the full-load contactor *K* and the overload release *L* to the field of both motors

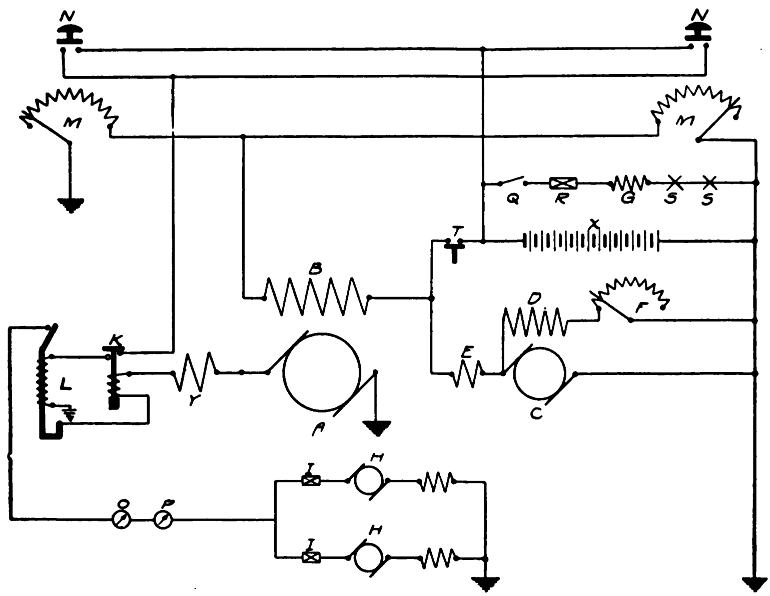

Fig. 41. Controls of Car Equipped with A.E.G. Engine

H and thence to ground. In the other controller positions the resistance is gradually cut out, increasing the motor voltage to 300. The graduation of the voltage is so worked out that it corresponds with the revolutions per minute and the speed of the car, and therefore the control losses are limited to those of shifting.

When the operator releases the handle *M*, the push button *N* immediately breaks the overload contact, cutting out both car motors and setting the solenoid brake. The handle, once released during the trip, must be brought back to the neutral position to close the overload contact by short-circuiting the overload relay.

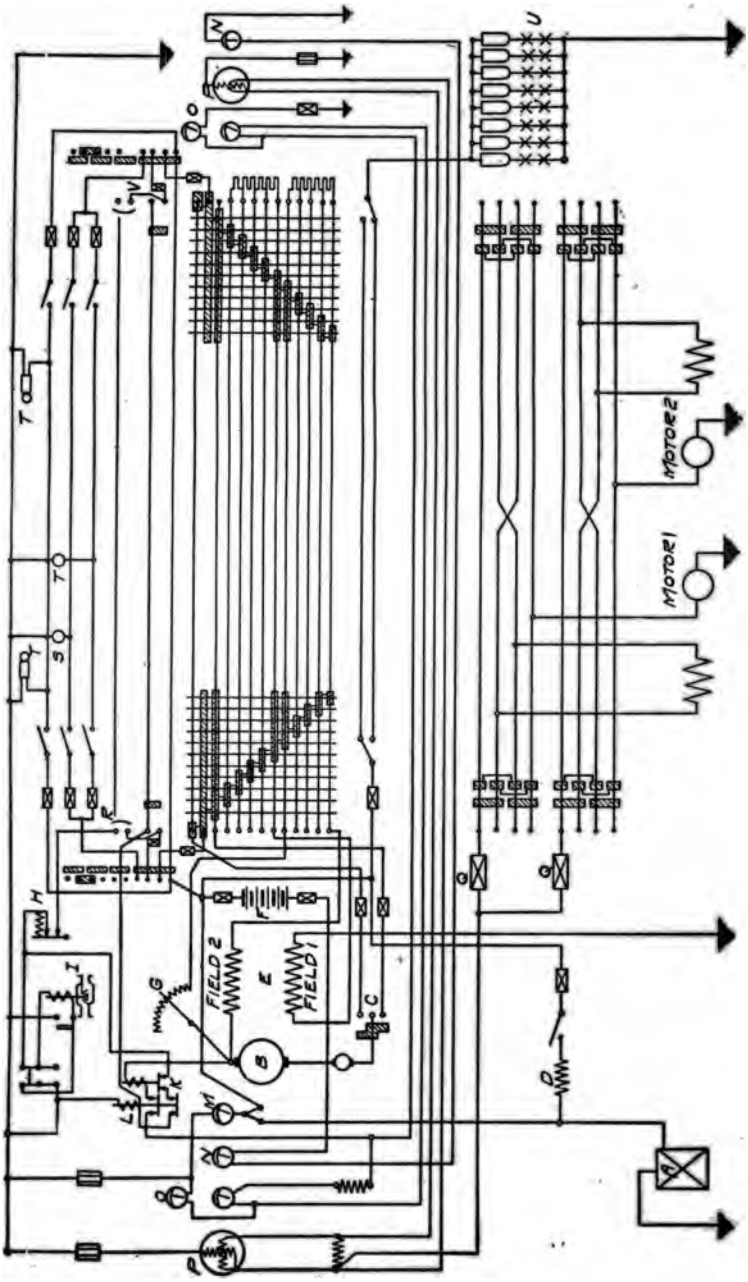

Fig. 42. Controls of Car Equipped with E.A.G. Engine

The Bergmann Elektrizitäts Unternehmungen E.A.G. use a new control system, Fig. 42, whereby the exciter is eliminated. The field resistance of the generator is divided into two parts; field *1* is connected to the battery, and field *2* is connected to the controller. After starting, when the handle is on the first point, it closes the circuit of field *1* and, at the same time, the engine speed increases as the car is set in motion. After the voltage of the generator reaches a certain point, the handle is moved to the second point and the field resistance *2* is inserted, increasing the excitation field of the generator. This releases the battery, in which the voltage in field *2* cannot increase, and, through further elimination of resistance, the voltage of the generator and the speed of the car increase and the battery is still further relieved until the current in field *2* is as large as in field *1*. At this point the controller connects both fields. Further increase of current in field *2* serves to charge the battery, etc. This arrangement has the advantage that the battery (an Edison) is used to furnish energy on the first stage of the trip and when the engine is running light, and otherwise serving to maintain a minimum voltage of the generator.

Driving Motors. On the rear trucks, Fig. 37, are mounted the two driving motors, which are entirely enclosed in dust-proof steel housings, driving the axles through a gear reduction of 1 to 4.3125. These motors are rated at 82 horsepower at 300 volts, 230 amperes, and 600 r.p.m., and on level tangent track they have driven the car at a rate of 45 m.p.h.

De Dion Bouton Car. The Hungarian Government adopted the De Dion Bouton gas-electric motor cars, Fig. 43, in 1906 for service on the Arad-Csanád and other railways, placing an order first for 50 and then following it up with a repeat order of 150, making a total of 200 at that time. The position of the generating machinery in the De Dion Bouton car may easily be seen in Fig. 44. It is arranged crosswise at the end of the car and supported on a separate base plate. The motive power is a four-cylinder four-cycle vertical internal-combustion engine (burning gasoline in 1906), and it is direct connected to a generator producing current at 550 volts. The equipment was designed and built for this high voltage in order to permit these cars to operate

over lines that were electrified and in conjunction with electric cars. Later the electric lines were abandoned or rather dismantled and the gas-electric motor car used entirely, owing to the fact that operating costs were lower and business increased. The cab contains the necessary switches and the controller as well as the engine accessories. In the new cars, the engine is placed horizontally instead of transversely as here shown, the latter position having been adopted in equipping the cars in service as space in them was limited.

The gas engine part of the equipment includes the fuel tank and also the radiators, which are mounted under the car. In winter the cylinder cooling water is used for heating the car before being sent through the radiator. The main fuel tank is placed over the engine and suspended from the roof, a hand pump being

Fig. 43. De Dion Bouton Gas-Electric Motor Car

carried as part of the equipment for pumping the fuel into this tank from the outside.

Electrical Equipment. The current from the generator is led to a series-parallel controller and thence to the two electric motors, one geared to each axle, the cars being of the four-wheel type so commonly used in Europe. The levers for operating the gas engine are grouped beside the controller, so that the engine ignition advance, throttle valve, etc. are all at the operator's hand. The motors have two salient and two consequent poles and the armatures are of the toothed-drum type. The commutators are mica insulated and thoroughly protected from the dirt and the damp. The whole machine is suspended from the frame of the car by a rod with spring stays. The gearing is by means of

sprockets and chains which are enclosed in a dust-proof and dirt-proof steel casing, the sprockets running in oil. Electric braking can be employed through the agency of the controller and there is also an air brake supplied by an axle-driven compressor. At all speeds of the car the engine is run at normal speed.

Performance. Tests were made at Arad, Hungary, with a car weighing 18 tons and having a seating capacity of forty. There were in the engine room two coupled engines and generators of 20 kilowatts each, but later a single set of 50 kilowatts was substituted. In the last five trials, 80 miles was covered each time and 2 miles of this was on grade. The engine worked for seventy minutes at stops and before starting; it was worked before starting in order to warm up the car by means of the engine jacket water, since the tests were made in midwinter.

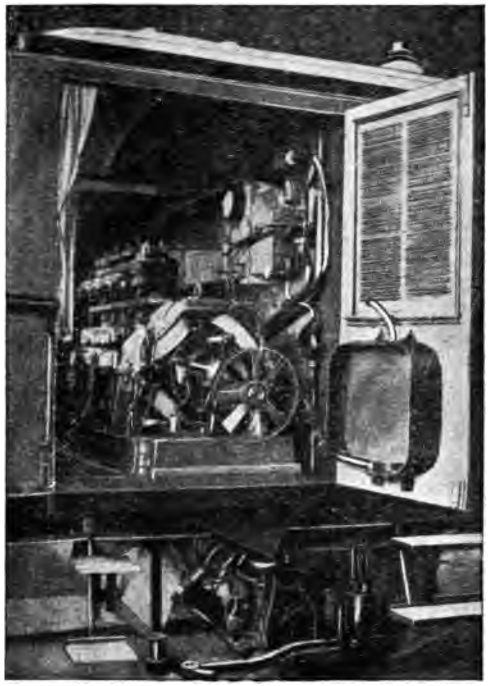

Fig. 44. Power Plant of De Dion Bouton Motor Car

It is interesting to note that the De Dion Bouton car was one of the earliest used in numbers and that railroads in European countries began operating self-contained railway motor cars before those in the United States. One of the factors that brought about the use of these cars was the need of a more economical operation, and the results are shown by the fact that these roads still operate such cars.

American Cars

Strang Car. The Strang car, now obsolete, Fig. 45, had a peculiar deck. Although it appeared to be of the usual steam

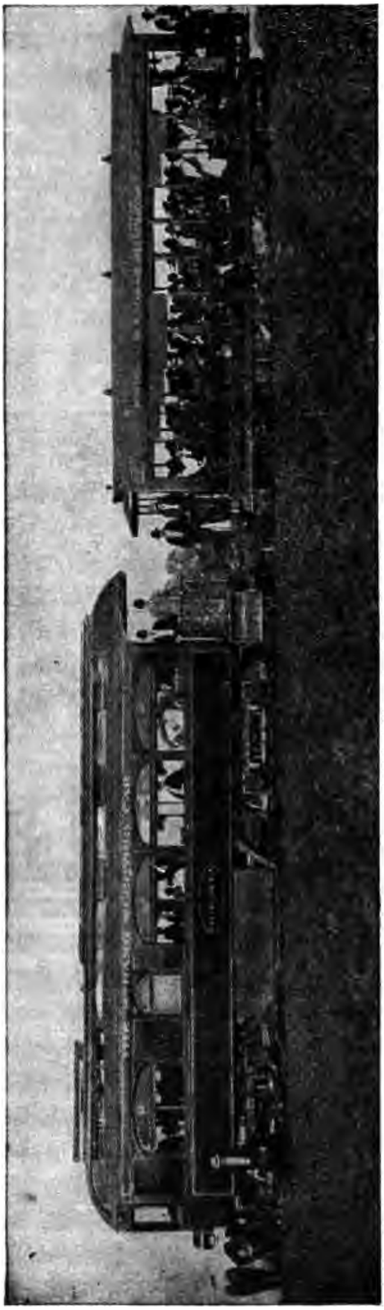

Fig. 45. Strang Gas-Electric Motor Car with Trailer

monitor type, it was in reality of the rounded, or "turtle back," type. The part above the deck or between the sides of the monitor was open and carried the radiators, exposing them to a free circulation of air. On the interior, the deck sash was arranged as a dormer window and avoided the tunnel-like effect of the regular "turtle back" deck.

The Strang system consisted of a gasoline engine, electric generator, storage battery, electric motors, and controlling devices so combined as to constitute a complete individual system. It is evident, Figs. 46 and 47, that the gas engine and the electric generator were coupled together on a common base plate, forming a self-contained generating unit. Directly from the brushes of the generator, main wires led to a controller of the series-parallel type. From the controller, wires led to the electric motors hung directly on the axles of the truck according to standard electric railway practice. The wires between the generator and controller were connected in multiple to a storage battery, and in one of the main

wires between the battery and the generator was a small rheostat which was used for temporarily converting the generator into a motor for starting the engine. The battery was meant to serve as

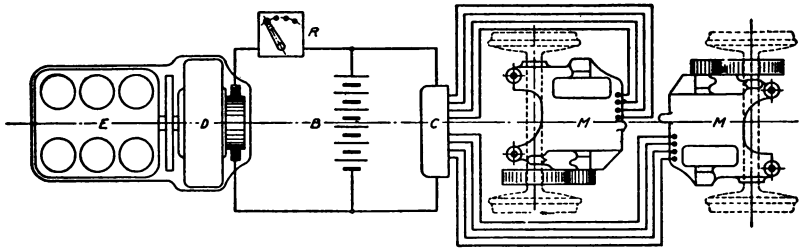

Fig. 46. Diagram of Principal Parts of Strang Motor Car

an auxiliary to furnish extra power in starting and accelerating, but later practice has taught that the generator fields may be controlled in such a manner as to eliminate the storage battery, thus saving the cost of its installation and operation.

The V-type six-cylinder four-cycle engine, Fig. 47, had a $10\frac{1}{2}$-inch bore, a 9-inch stroke, and a continuous rating of 150 horsepower at 425 r.p.m. and was direct connected to an 85-kilowatt, 250-volt direct-current shunt-wound interpole generator. On the forward trucks were two 100-horsepower 250-volt series-wound, interpole motors. The storage battery was composed of 112 cells and was of 300-ampere-hour capacity. The General Electric type M control system was used and Westinghouse automatic air brakes were employed. The cooling and heating system consisted of an electrically driven centrifugal pump, which circulated water through radiators on the roof and, when desired, through the heating coils in the car.

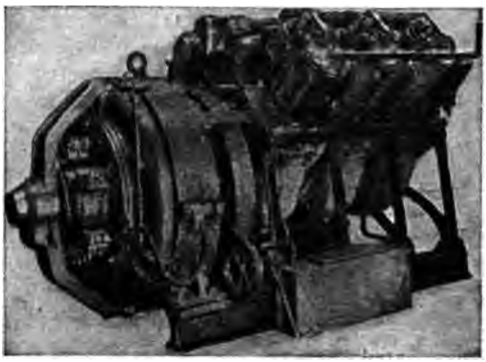

Fig. 47. Engine and Generator Unit of Strang Motor Car

General Electric Car. The most extensive builder of the electrically driven type of internal-combustion engine cars has

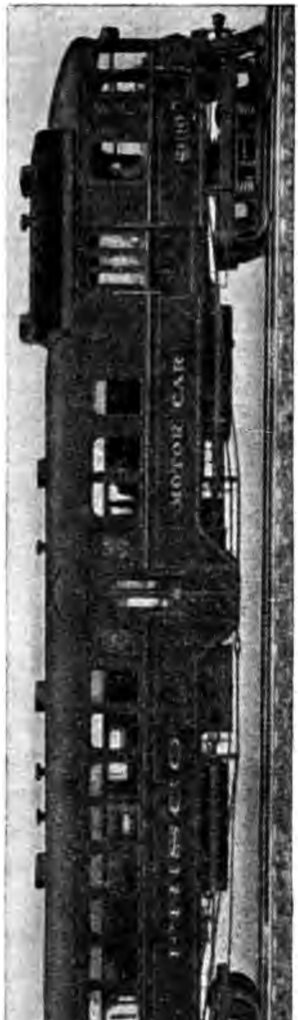

Fig. 48. Gas-Electric Motor Car Used on St. Louis & San Francisco Railroad

been the General Electric Company, of Schenectady, New York, which began its development of gas-electric cars in 1908 with the construction of the first car for the Delaware and Hudson Railroad. This was a standard railway car built by the Barney & Smith Car Company and had standard railroad trucks. The engine for the first car was purchased in England, as there was no suitable engine built in the United States. The electrical equipment was built by the General Electric Company and proportioned on the results of previous experience with heavy railroad equipments. After the first car had been operated 5000 miles, a second car was constructed, the entire equipment of which was built in the United States and from which the present General Electric designs have been evolved. The car bodies, Fig. 48, are built of all steel and designed for a combination of strength and lightness. The front end is rounded to reduce wind resistance when operating at high speeds, and either a center or end entrance is supplied to meet traffic requirements. The cars are built in lengths from 40 to 70 feet over all and weigh from 40 to 50 tons.

The power plant, Fig. 49, is located in the engine room at the front end of the car and consists of an eight-cylinder V-type four-cycle gasoline engine direct connected to a 100-kilowatt generator and running

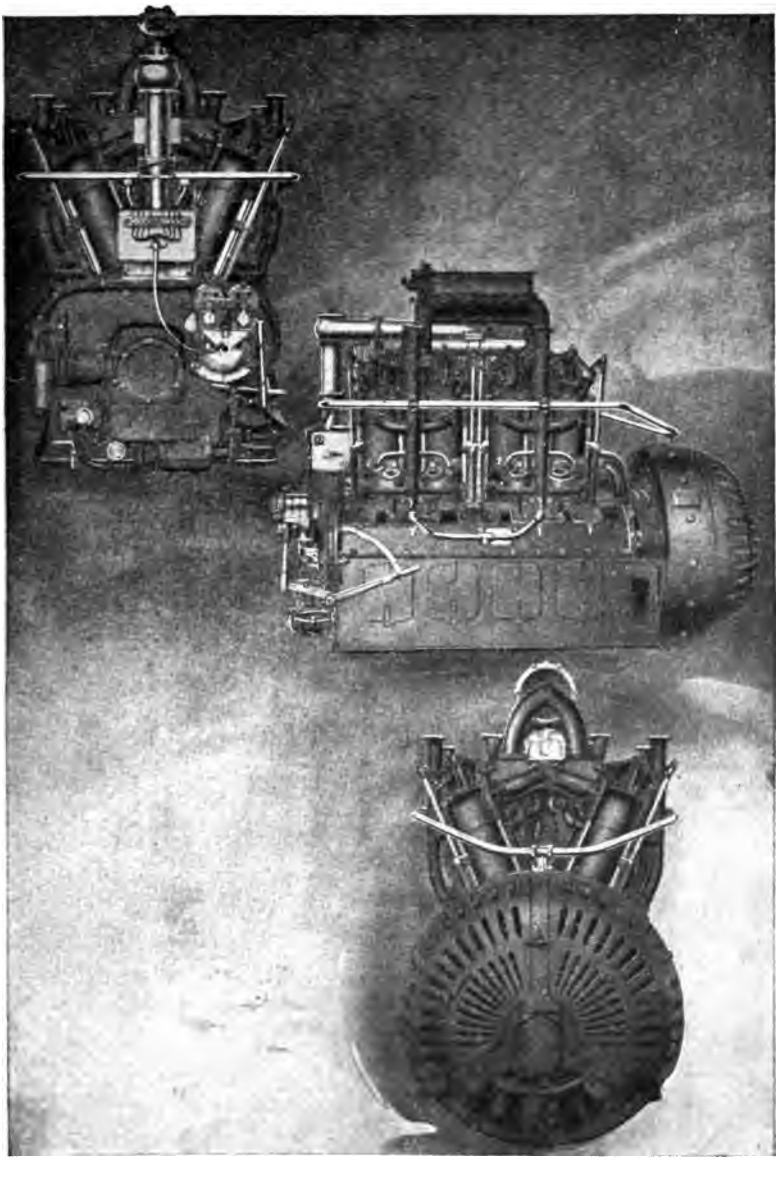

Fig. 49. Views of Power Plant of St. Louis & San Francisco Railroad Motor Car

at 550 r.p.m. This generator is built essentially to carry a wide range of output in current and voltage, so that the output may be varied from 400 amperes at 250 volts to 125 amperes at 800 volts.

Motor Truck. The trucks are of the equalizer type with swing bolster and are suitable for high speeds. One of these trucks is the motor truck, which is designed to carry two electric driving motors. This truck is placed under the front end of the car and carries the weight of the engine-room equipment in addition to the weight of the motors. In this case, 60 per cent of the entire weight of the car is carried on the driving wheels. In some cases, however, the motor truck is placed at the rear of the car under the passenger compartment and then carries only about 40 per cent of the weight. The motor truck is equipped with two General Electric motors, No. 205, of 100 horsepower each. This motor is a commutating-pole type and is suitable for a wide variation in operating voltage. The gearing is specially selected for this service; the ratio is low enough so that the maximum car speed will not develop an excessive rotative speed of the armatures and also high enough to obtain the requisite starting effort without imposing excessive overloads on the motors.

Fig. 50. Controls of St. Louis & San Francisco Railroad Motor Car

Control. The cars are designed for single-end operation only. The engineer's seat is located at the right-hand front window in the engine room, Fig. 50, and the controller and throttle valve handles are placed directly in front of him. The controller is a combination of engine and generator controls, with the different levers placed vertically above each other and operating about the same center line. The highest of the levers is the throttle lever, which controls the supply of gasoline to the engine and, consequently, the speed and power. Directly beneath this is the electric control lever, which on the first part of its range connects

the two motors in series. Successive steps then raise the generator voltage from 250 on the first step to about 700 volts on the seventh step. In passing into the next step of the controller, the voltage is reduced to about 250 and at the same time the connection between the motors is changed, putting them in multiple with each other. On the remaining steps the two motors are running in multiple; the generator current is divided between them and each is actuated by the full generator voltage. This voltage is raised in successive steps up to the maximum of about 800 volts on the thirteenth step. Two final steps are provided, in addition to those just mentioned, and they are suitable for particularly high speeds on level tangent track with shunted motors.

The engine is started by admitting air to the cylinders, which is done automatically on the first opening of the throttle. As soon as the engine turns over and the first charge of gasoline is exploded in the cylinder, the air for starting is automatically shut off. The air reservoirs are charged by an air compressor which is driven from the main crank of the engine and which also furnishes air for the brakes and the whistle. A small independent engine-generator set is furnished and supplies current for lighting the car. It is also connected to an auxiliary air compressor, which, in case the pressure in the main reservoirs is low, may be used to charge them again, for example, if the car has been standing for some time and it is desired to start the main engine.

Ewbank Car. The Ewbank car, Figs. 51 and 52, is built by the Ewbank Electric Transmission Company, of Portland, Oregon, and is of the same general type as the General Electric Company's cars. It was put in demonstrating operation on railroads in the West in 1914, particularly on the Spokane, Portland, and Seattle Railroad. The power plant consists of a 350-horsepower gas engine direct connected to a direct-current generator and arranged to start on gasoline and then to run on distillate. The trucks are each provided with two 75-horsepower motors, giving traction to all wheels. In general, the Ewbank is similar to other gas-electric cars.

ELECTRO MECHANICAL DRIVE

Daimler Car. *Dynamotor Equipment.* The designer of the Daimler car first brought out an equipment in which the engine

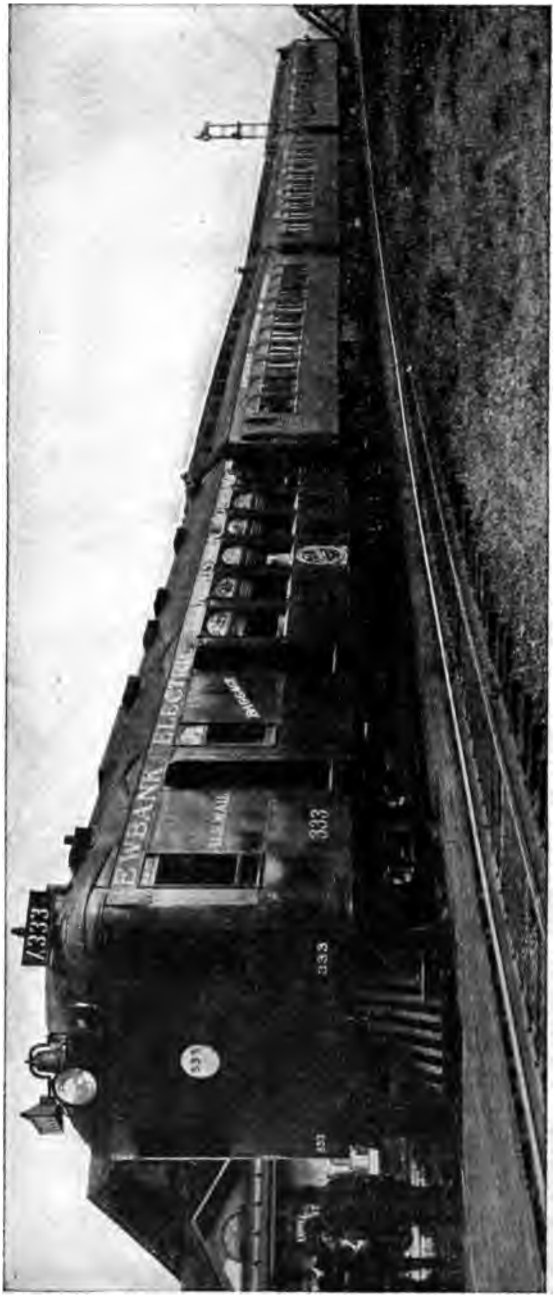

Fig. 51. Ewbank Gas-Electric Motor Car with Three Trailers, Total Load 246$\frac{3}{4}$ Tons

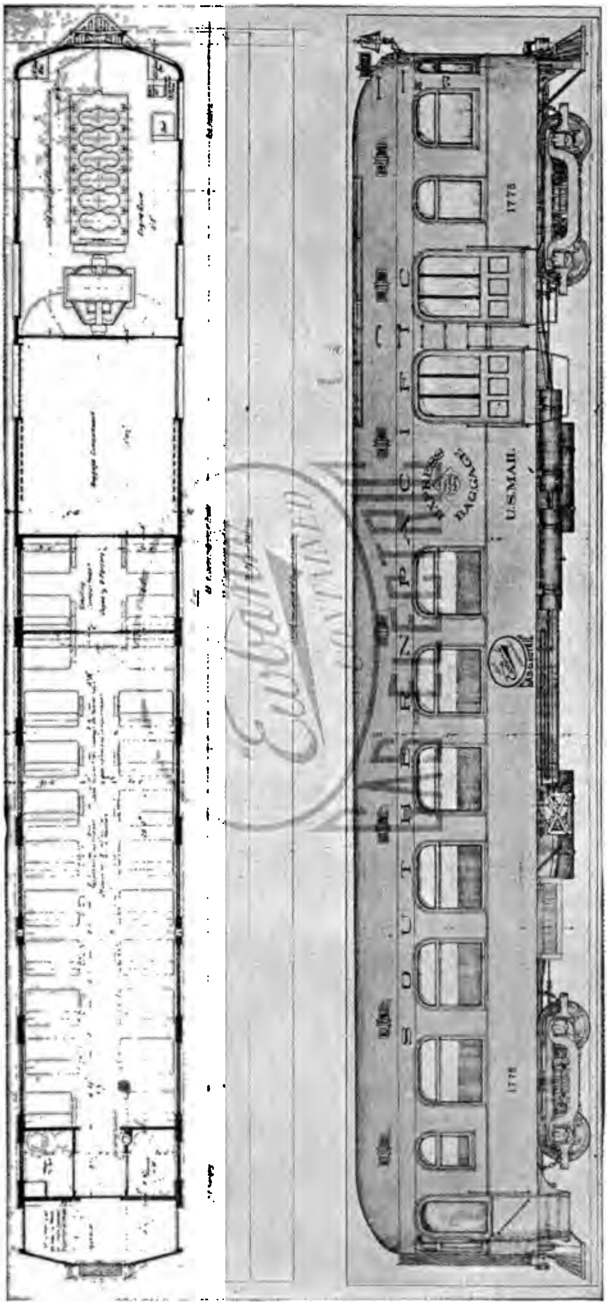

Fig. 52. Plan and Elevation of Ewbank Motor Car

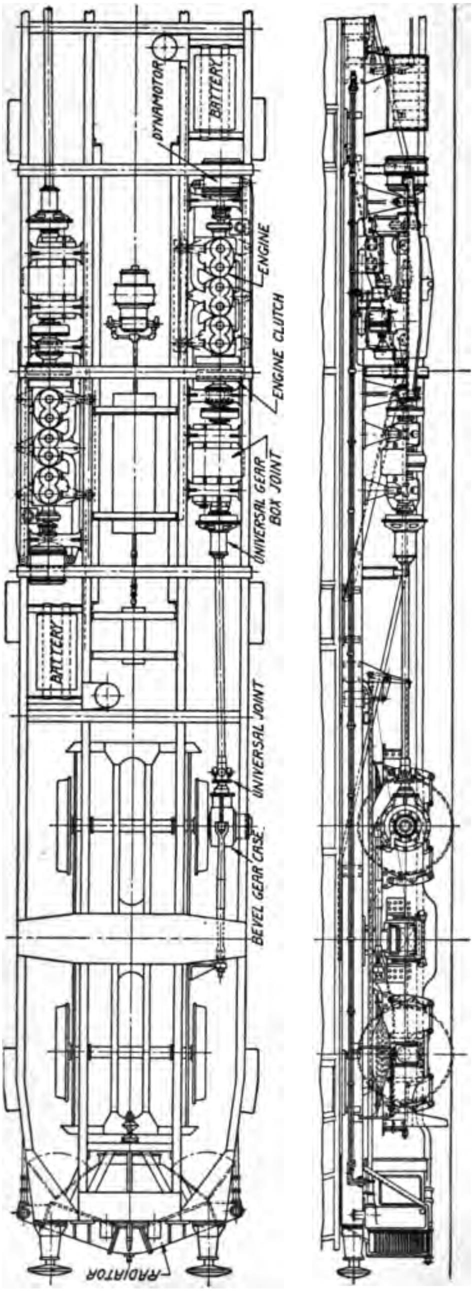

Fig. 53. Diagrams of Arrangement of Equipment on Daimler Car

power was transmitted to the wheels through the armature of a direct-current machine capable of acting as a generator or a motor, Fig. 53. A storage battery was connected across the armature so that as long as the voltage of the generator terminals exceeded the potential difference across the battery, the energy in excess of that required to propel the car was used to charge the battery. When, however, the torque required to move the car exceeded that which the engine was developing at that speed, the speed of the engine was reduced and the storage battery discharged through the armature of the electrical machine, which, for the time being, was converted into a motor and assisted the engine. As soon as the car attained engine speed, the electrical machine again became a generator, the engine taking the full load and the generator charging the batteries again.

On account of the dual function of this machine it was called a *dynamotor*.

At first sight this system would appear to be the complete solution to the vexed question of transmission. A perfectly smooth variation was attained and at the highest speeds the engine torque was transmitted to the wheels with no more loss than in the case of a purely mechanical drive with the so-called direct, or high-speed, drive. By means of the dynamotor the engine was started in either direction. The storage battery was also used for lighting the car and other auxiliary purposes. The rheostat in the dynamo field circuit provided speed control and the throttle lever was used in the ordinary way. In the practical working of this system the storage battery had to receive constant attention, owing to the violent alternations of the direction and value of the current, and the main danger lay in the excessive charging currents. Moreover, if the car was in constant service requiring frequent stops, the engine had to be considerably larger than otherwise required, as the periods during which it maintained the charging speeds of the generator were not of sufficient duration to replace the energy given up during the frequent periods of acceleration.

The expense of the dynamotor equipment was considerably in excess of that of the purely mechanical drive, as the gear case had to be replaced with a much more expensive electrical machine, and as the clutch, drive shaft, universal joints, and final bevel gear drive were retained and a storage battery was added. One of the interesting features of this equipment was the automatic device for slipping the magnetic clutch during starting and acceleration, thus saving the storage battery from excessive discharges that would otherwise occur. This device consisted of a solenoid in the main armature circuit, the plunger switch inserting a resistance in the clutch circuit when the solenoid was energized by excessive discharge from the battery.

On account of the high cost of the dynamotor equipment and the many troubles that occurred unless it was given constant and close attention, it was abandoned for the gear transmission type, as shown in Fig. 54.

Gear Transmission System. The equipment with gear transmission has two engines mounted on opposite sides of the under-

frame and carried in a spring-suspended cradle. Each power unit, comprising a six-cylinder engine, is arranged to drive independently one of the axles on each truck, a bevel gear arrangement being mounted on a prolongation of the driven axle. The gear transmission is direct connected to the engine through a magnetic clutch, and the power is transmitted from there to the driven axle through a longitudinal shaft and universal joints, as shown at Fig. 53. On the opposite end of the engine from the transmission is mounted a generator and motor combined, the function of which

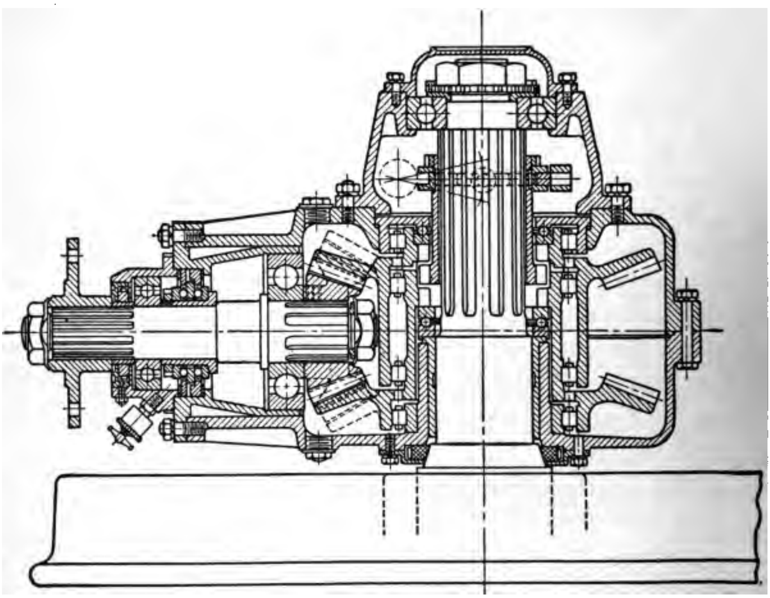

Fig. 54. Bevel Gear Drive on Wheel Journal

is to provide means for starting the engine, charging the batteries for lighting the car, and operating the air compressor. The whole power plant and transmission is so mounted on the spring cushions as to relieve the car of all vibrations and gear noises. The gear transmission was finally adopted after considerable experiment and study.

The car is fitted with an engineer's cab at each end and the whole equipment is arranged symmetrically. The reversal of the car direction is through double bevel gears and jaw clutches. The most salient features are the magnetic clutch actuation, as previously described, and the use of the gear transmissions in tandem.

The trials and tests of this car showed a fuel consumption of 0.6 pint of gasoline per brake horsepower hour at a car speed of 18 m.p.h.; the total consumption was 72 pints, or 9 gallons, that is, 5.33 miles per gallon, or 160 ton miles per gallon.

The Daimler Company, of England, has constructed a number of these cars, which are in use on English railroads and are giving excellent service.

Thomas Car. The Thomas car is of the electro-mechanical type, that is, the drive is by means of a dynamotor in starting and then through the gear system and the main drive shaft, much as in the Daimler.

The motor car, Fig. 55, is of the double-truck type, with two four-wheel trucks, and has a total length of 62 feet 6 inches and a

Fig. 55. Thomas Motor Car Used on New Zealand Government Railways

width of only 7 feet. The trucks have a wheel-base of 5 feet 10 inches with truck centers of 38 feet, and the car was built for a gage of 3 feet 6 inches. The complete weight of the underframe, engine, and trucks is only 18 tons, and the engine, transmission, and radiators weigh only 7 tons. The motor car was designed to handle two 25-ton trailers and for use on the New Zealand Government Railways. The specifications called for a car capable of hauling one loaded 25-ton car (the gross load being 60 tons) up a $2\frac{1}{2}$ per cent grade at 15 m.p.h. and having a maximum speed of 40 m.p.h. on level track.

Engine. The engine is an eight-cylinder V-type and develops 200 horsepower at a normal speed of 900 r.p.m. but is capable of 1500 r.p.m. The cylinders have a bore of 7 inches and a stroke

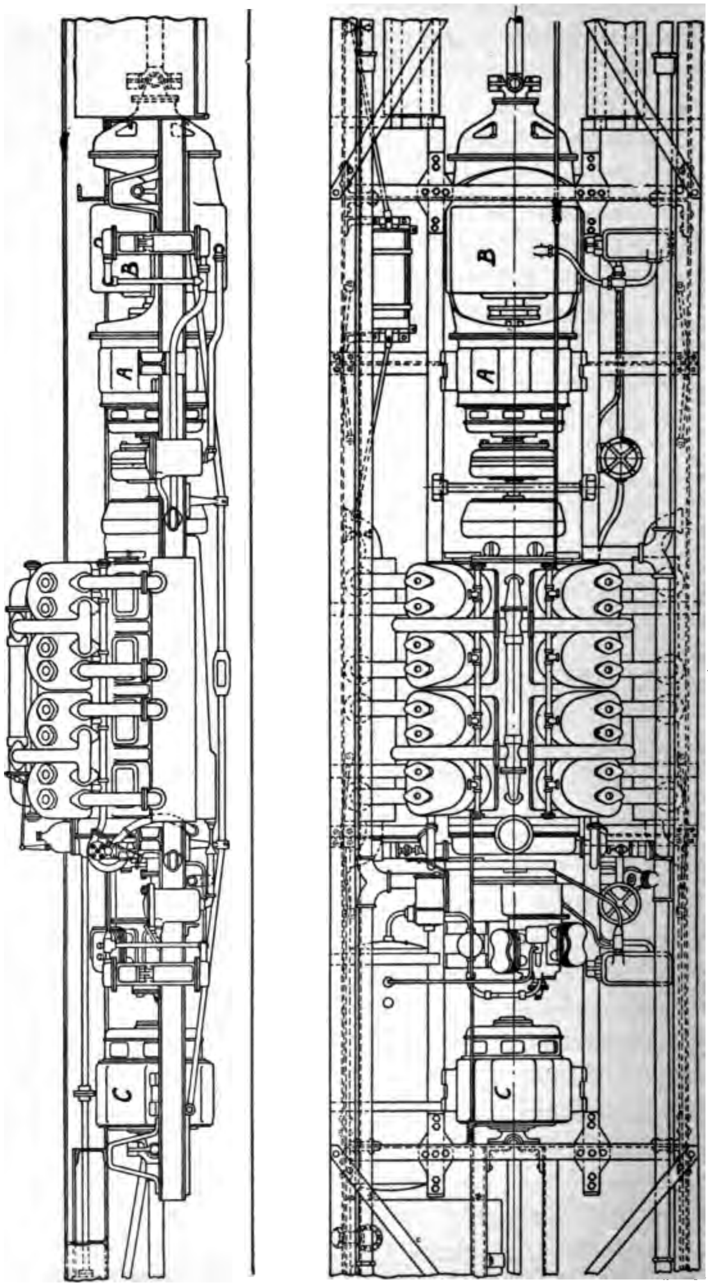

Fig. 56. Power Plant of Thomas Car

of 8 inches and are set so that the opposite cylinders act on the same crank, one cylinder of each pair having a forked connecting rod which has brasses on the outside of the straight connecting rod of the other cylinder. This method decreases the length of the engine. The main inlet manifold lies in the V between the cylinders and has a Claudel-Hobson (English) carburetor at each end. These carburetors work in parallel. Two magnetos are fitted, one for each set of cylinders. The valves are situated on the outside of the V, which is an unusual arrangement, but in this case it increases their accessibility, Fig. 56. Two mufflers are used, one for each set of cylinders, and they are located between the bottom of the crankcase and the underframe. Gasoline is the fuel, and it is claimed that 200 ton miles per gallon can be obtained on an average run, including grades.

The radiators are fixed at each end of the car and are so arranged with ducts that there is an ample flow of air through both radiators, irrespective of the car direction. In addition to the water-cooling radiators, there is one for cooling the oil used in the engine and one for cooling the lubricating oil of the planetary gearing which forms a part of this system. Circulation of the water is by two centrifugal pumps and that of the oil by gear pumps. These pumps are all driven by the engine in such a manner that the reversal of the engine does not affect the pump motion. When the engine is reversed, only the crankshaft reverses its direction of motion.

Transmission. The Thomas transmission consists essentially of planetary gears and two electrical machines, the drive being transmitted from the engine to the car wheels in part mechanically and in part electrically. The idea of this arrangement is to obtain the flexibility of the electrical drive and at the same time retain the direct mechanical drive at high speed. This permits the electrical drive to be of considerably smaller capacity than would be required with a full electrical transmission and cuts down its weight and losses. The control is simple and the efficiency of the equipment is high. The engine is located at the center of the car body with the transmissions placed at each end, Fig. 56.

The first electrical machine *A* and the planetary gears *B* are at one end of the engine, and the second electrical machine *C* is

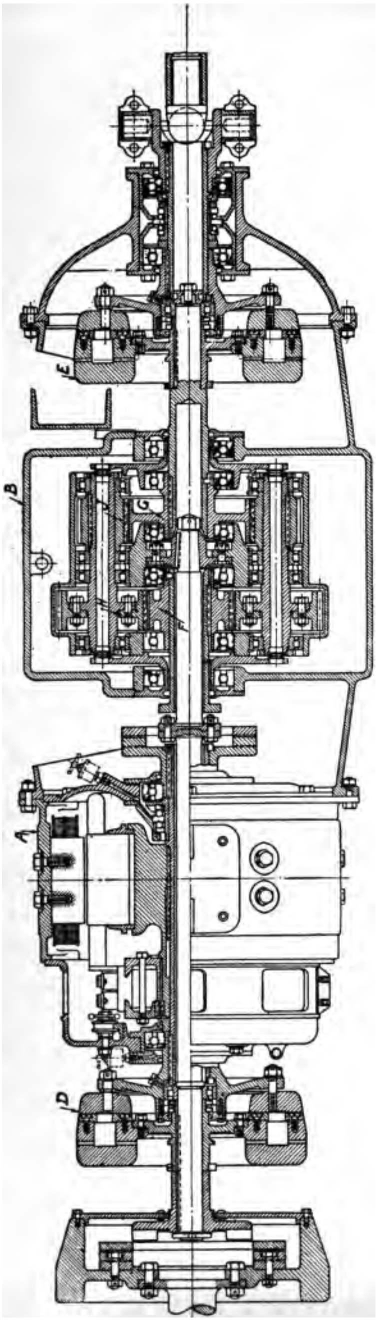

Fig. 57. Transmission Details of Thomas Car

at the other end, Fig. 56. The planetary gears and the first electrical machine *A*, together with the magnetic clutches which form part of the transmission, are built to form a single rigid unit, Figs. 56 and 57. The second electrical machine *C* is not illustrated except in the general drawing, Fig. 56, and is to all intents and purposes a duplicate of machine *A*.

Referring to Fig. 57, the gears shown have the engine on the left-hand end. The engine is rigidly connected to the outer drum of the planetary gears *B*, and on this drum are mounted bearings for two shafts which carry the planetary gears *H* and *J*. Each shaft carries two gears of different sizes, so that the two rotating together always form a pair. The larger planetary gears *H* drive on the sun gear *F*, which is secured by a hollow shaft and connected by a coupling (not shown) to the hollow shaft carrying the armature of the electrical machine *A*.

The smaller planetary gears *J* drive on the sun gear *G*, which is connected through a magnetic clutch *E* to the transmission shaft shown at the right-hand side of the illustration. A second magnetic clutch *D* is at the left-hand side. This permits the

engine shaft, which is connected rigidly to the drum of the planetary gears, to be coupled to the hollow shaft which carries the smaller sun gears *F* and the armature of the electrical machine *A*. The transmission shaft at the right-hand side drives the outside axle of one truck. The final drive is by a bevel and spur gear reduction. The second electrical machine *C*, Fig. 56, is connected electrically to the first and receives no mechanical drive from the engine but drives the outside axle of the other truck through a transmission shaft.

Operation. The car is governed by the main controller, which gives twelve speeds, and an auxiliary switch, which is operated in the same way as a clutch pedal on an automobile. The manipulation of the car in the various stages, beginning when it is standing without the engine running and ending with the car running at full speed is as follows: When the engine is not running, both magnetic clutches *D* and *E* are disengaged. To start, the controller is moved to the "start engine" position. This connects the storage battery, which is carried on the car, across the electrical machine *A*. The auxiliary switch is then closed, which energizes the magnetic clutch *D* between the engine and the electrical machine *A*. The battery drives the machine and starts the engine. The magnetic clutch is then released, and the running engine now drives the drum of the planetary gears, the gears, however, running idle. The auxiliary switch is then moved to the "on" position, and this energizes the magnetic clutch *E* which connects the sun gear *G* to the transmission. As the transmission is held, owing to the resistance of the car, the result is that the first electrical machine *A* is driven in the reverse direction from the engine owing to the action of the planetary gears.

The main controller is then moved and makes connection between the electrical machines *A* and *C;* resistance to the motion of the first electrical machine *A* is introduced and, as a consequence, it is slowed down. Now, as a result of the action of the planetary gears, the large sun gear *G* is driven and the car starts. At the same time a starting torque is inversely applied to the second electrical machine *C* by the first machine *A*. This assists in starting, and part of the torque is applied mechanically to the driving wheels through the planetary gears and part electrically

through the second electrical machine. By moving the controller over its successive notches, the load on the first electrical machine is gradually increased until it slows down and comes to rest. Owing to the fixed ratio of the gearing, this means that the large sun gear *G* gradually moves faster, causing the car to increase its speed. The same increase in speed takes place in the second electrical machine as a result of its connection to the first. During this action, more and more of the transmission becomes mechanical and correspondingly less of it electrical. When the first electrical machine stops, the whole of the transmission is mechanical.

To increase the speed of the car still further, the functions of the two electrical machines are reversed and the second machine *C* feeds the first machine *A*. Then machine *A* begins to rotate in the opposite direction, and again, as a result of the fixed ratio of the gears, the large sun gear *G* is driven still more rapidly and the car speed further increases. This action goes on until the armature of the first electrical machine is running at the speed of the engine and in the same direction. The magnetic clutch *D* connecting the engine and the first machine is then energized, and a direct drive is obtained from the engine to the driving wheels, since the planetary gears lock. This is the full-speed position, and the electrical circuit is cut out. When the car is traveling on high-speed gear, the two electrical machines are inoperative and can be used for any useful purpose, such as charging the storage battery, this battery being used for starting and lighting. The battery is not used for assisting the car at any time. The controller has a notch above full speed, which is used to charge the battery.

To stop the car, the controller is moved back and both magnetic clutch circuits are broken by the auxiliary switch. To run in the reverse direction, the engine is reversed. The controller has two reverse notches for short-distance reversing, as in switching. When these are in use, the mechanical transmission is cut out by disengaging the right-hand magnetic clutch *E* and a purely electrical drive is obtained from the first electrical machine *A* to the second machine *C*. The change-speed electrical control is all carried out in the fields of the machines, so that no heavy cur-

rents are handled. The car can be operated from either platform. Westinghouse air brakes are used, with an air compressor direct connected to the engine crankshaft.

HYDRAULIC DRIVE

Extent of Use. Although the hydraulic transmission has been tried out several times for automobile service and has rendered excellent results and shown high efficiency, its application to the self-contained railway car has been limited. The reason for this has been principally the lack of understanding on the part of the designer of the movement as to actions of a railroad truck. Hence when he has attempted to apply hydraulic transmission to trucks he has seemed to utterly disregard the conditions existing. There is a great difference in the application of a transmission to an automobile and to a railroad car. Experience and experiment are part of the requisites of the designer who would make application of hydraulic principles to the transmission of power, especially in railroad service.

Hele-Shaw Transmission. The Hele-Shaw transmission possesses many advantages for railroad service, and in 1913 Messrs. McEwan-Pratt & Company, of England, constructed and built a standard-gage railroad car equipped with one of these transmissions. The car was built for service in Canada and to operate on a circular track. It is 33 feet over all in length, 8 feet 3 inches in width, weighs 20 tons, is of the double-truck type, and has a seating capacity of thirty-six.

The power plant is a six-cylinder gasoline engine of 140-millimeter bore and 156-millimeter stroke (5.5118 inches by 6.1417 inches), giving a brake horsepower of 103 at 1150 r.p.m. The engine is arranged transversely across the front end of the car in a special compartment, or engine room, Fig. 58. This internal-combustion engine is direct connected to and drives the hydraulic pressure generator, or pump, which supplies pressure to two hydraulic motors in parallel on the rear trucks. This transmission is quite simple in construction, as all the parts are cylindrical, and results in a high efficiency, owing to the means adopted to reduce friction. A further simplification lies in the fact that there are no operating valves in the pump, motors, or pipe line.

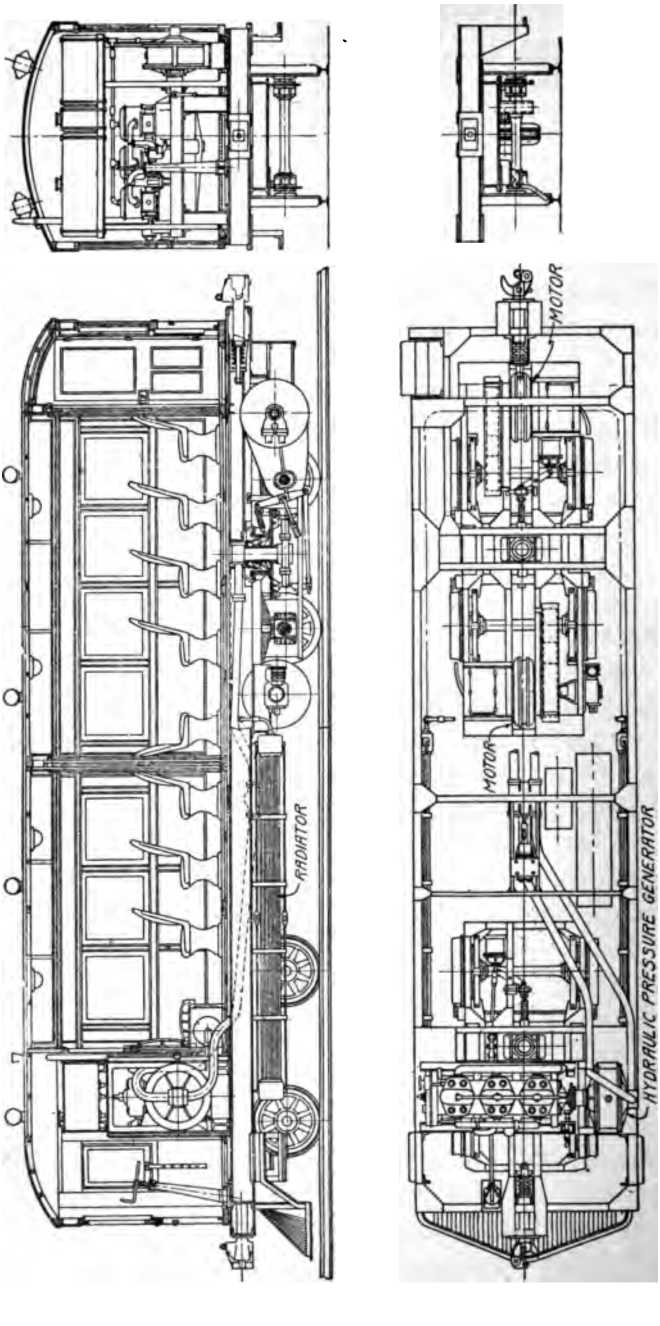

Fig. 58. Arrangement of Parts for Hele-Shaw Transmission

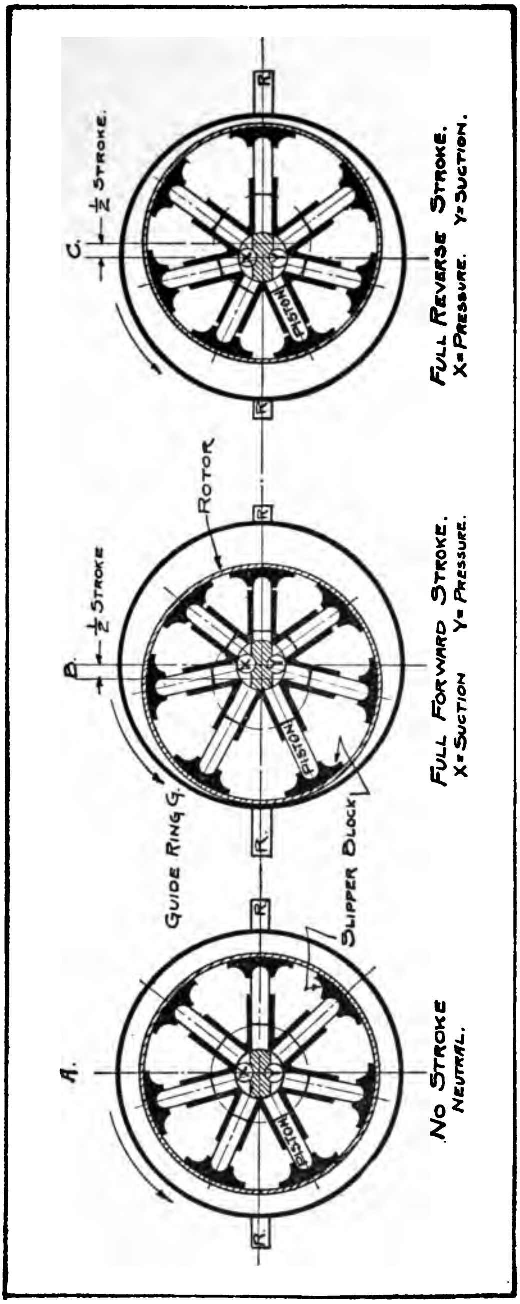

Fig. 59. Diagram Showing Working Operations of Hele-Shaw Transmission

Pressure Generator. T[illegible] c[illegible] ssure generator, or pump, is shown in [illegible], from [illegible] it [illegible] be seen that the rotor, or cylinder body, comprises a series of radial cylinders revolving on a fixed shaft. In the length of this shaft two passages X and Y are formed, connecting the two ports while alternately communicating with the cylin[illegible]s as they rotate. Mounted in the casing of the cylinders is a gui[illegible]e ring G, which can be displaced horizontally to either side of the vertical center line of the cylinder body by means of the rod R. This guide ring forms a bearing on its inner circumference for a series of blocks, which form abutments for the pistons fitted to the cylinders.

In the first position, Fig. 59 A, the guide ring is concentric with the cylinder body, and when the latter is rotated as shown by the arrow, there being no relative motion between the guide ring and the pistons, no pumping action takes place. If the guide ring is moved to the second position Fig. 59 B, that is, to the left of the center, the pistons above the center line move outward in their cylinders and suction takes place through the passage X and delivery through the passage Y. By moving the guide ring to the opposite side of the center line, as shown in the third position, Fig. 59 C, the direction of flow and delivery of the liquid is reversed, thus giving delivery through X and suction through Y. It will readily be understood that with a partial movement of the guide ring to either side of the center line and with a constant speed of rotation, the ratio of pumping can be regulated as desired. It is further obvious that the reversal of flow can be effected without shock, since the passing of the guide ring from one side to the other brings the flow down gradually to zero before the change can be made.

Motors. The motors working in connection with this pump are of similar construction but are provided with fixed guide rings and, consequently, have a constant stroke. By connecting the pump and motors in a closed circuit and by suitably adjusting the guide ring of the former, a fine graduation of speeds of the motors at a constant speed of the pump may be obtained in either direction.

The pump and motors are connected by two pipes, one connecting the passages X and one the passages Y, that is, similar

passages are connected. As is usual in transmissions of the kind, the fluid is oil, and a certain amount is allowed to pass to the working parts to ensure perfect lubrication. In the case of the pump, the superfluous oil is drained from the casing to a receiving tank by means of a small pipe. It is returned to the system again through nonreturn check valves, the valve corresponding to the suction side of the pump always coming into action.

Distinctive Feature of Design. The general design of the motors and pump is shown in Fig. 60, and from the following description it can be seen that although the principle of operation follows that just given, an important modification is made in the construction of the guide ring. The center shaft, which is of hardened steel, is fixed in the outer casing of the pump and is accurately ground to a running-fit for the cylinder body, which rotates on it. At the outer end of the shaft, two pipe connections are provided, communicating with the two passages X and Y, which terminate at the center line of the pump in two ports. In the pump shown are seven cylinders, these being bored radially in the disc-shaped cylinder body, which is driven by the fixed shaft through the side of the casing and further supported by the ball bearing shown. The outer edge of the disc is reduced in thickness, and slots are formed in the sides of the cylinders to allow the wrist pins W, carried by the pistons, to pass through. To each end of the wrist pins are fitted blocks S working in the floating ring U, which forms an essential feature of the design.

In earlier variable-stroke pumps of similar design, the guide ring was stationary, with the result that an excessive amount of sliding friction existed between this ring and the blocks or their equivalent; but in working out this design, Dr. Hele-Shaw hit upon the idea of mounting the ring on roller bearings, and thus reduced the friction to a negligible quantity. The set of roller bearings B are mounted in each of the sliding frames T fitted in the casing—shown dotted—and these bearings carry the floating guide ring U, leaving it perfectly free to revolve on its axis. The only motion of the blocks is due to the slight difference in the angular movement of the cylinder body and the floating ring, which is proportional to the stroke of the pistons. The two sliding frames are connected to the shaft E, which passes through the

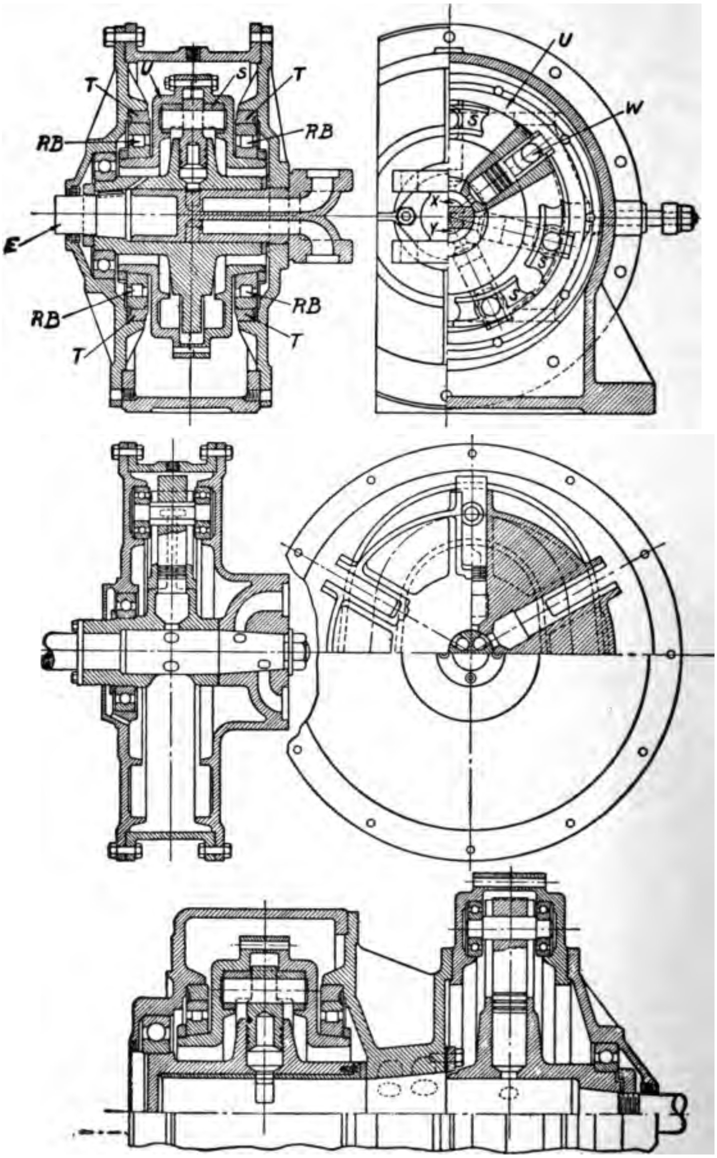

Fig. 60. Details of Hele-Shaw Hydraulic Pump and Motor

casing and is coupled to the gear controlling the stroke and the direction of delivery of the pump.

A number of these transmissions have been put into practical use and, on account of the efficient lubrication, wear is practically nonexistent. No packings are used in the construction and the leakage, which ensures efficient lubrication, is comparatively small.

The motor is practically the same as the pump, except that the floating ring is replaced by a fixed one, so formed that the pistons make two strokes to each revolution of the motor. As previously explained, the motor has a fixed stroke, and, in order to obtain a uniform angular velocity of the oil, seven (an odd number) pistons are provided and the guide ring is of special form. The blocks are replaced with roller bearings, while the central shaft is formed with four ports, which connect in their respective sequence to the oil pipes from the pump.

The oil under a maximum pressure of 2000 pounds per square inch is transmitted through a heavy steel pipe to the two hydraulic motors coupled in parallel on the truck, and the rotary motion of the motors is transmitted to the axles through a heavy steel chain and sprockets. As the speed of the oil motors is proportional to the amount of oil delivered by the pump, a continuous, variable, and reversible transmission is provided. Safety valves are provided on the pipe line so that any undue stress that might be thrown on the transmission is automatically relieved.

The efficiency of the pump, taken separately on truck trials, was 90 per cent and that of the motor 95 per cent. There was practically no loss by heat in the transmission, and the oil in the pipes, generator, and motors needed no cooling.

By reason of the sharp curves over which this car runs, it was necessary to provide double trucks, and the pivoted socket joint, Fig. 61, was introduced. Locomotive engineers with experience on articulated locomotives may regard this joint with mixed feelings. It may, however, be pointed out that the manner in which the whole thing is mounted is calculated to prevent any relative motion between the parts, except in the vertical and horizontal planes. In developing this system of rigid connections combined with the swing joint for the oil supply, a considerable amount of experimenting was carried out with various kinds of

flexible tubing. As a result, it was discovered that although it was possible to obtain tubing that would withstand the high pressure, on application of this pressure the tube ceased to be flexible and was of no further use for the purposes intended. Since this point may not be generally recognized, it is considered of sufficient importance to be mentioned in this connection. Another feature of the system is a by-pass for the oil, which is automatically actuated by means of cylinders when the brakes are applied, thus preventing damage to the hydraulic motors. Tests of the car proved the claims made for it.

Advantage of System. The advantage of the hydraulic drive is that a great starting effort can be applied to the driving wheels without the shock which so frequently accompanies the use of a clutch and gearing. Also, the speed ratios are infinite from zero to maximum and the car is started, stopped, and reversed with the greatest ease. This type of drive was built to the order of John Birch & Company, of 2 London Wall Building, London, E. C.

Zeitler Gas-Hydraulic Motor Car.* Self-contained railway motor cars have followed automobile practice closely as far as the engine and the transmission are concerned, and the placing of these parts has been similar to that in the first electric cars, in which the electric motor was placed in the car and belted or geared down to the axles. With the engine in the car body many difficulties arise, as the engine occupies a special room 12 to 15 feet in length in the front end of the body, practically one-fourth the length of the average car body. Designers of foreign cars have attempted to solve the problem of engine location in various ways and in the Deutz equipment, Fig. 33, the engine is located under a hood on a portion of the truck which projects beyond the car body.

All methods of transmission have been introduced between the engine and the driving wheels but the mechanical and electric types predominate owing to their ease of application and their close association with allied mechanical and electric features of railway equipments.

In designing the Zeitler equipments, it has been the purpose to eliminate, if possible, current objections to the internal-combus-

*Zeitler Gas Car and Locomotive Company, 20 West Jackson Boulevard, Chicago.

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tion. engine as a motive power. A simple high-speed engine has been designed and, together with the hydraulic transmission and multiple-unit control, the equipment will fit all types of cars and locomotives. The entire control of the engine and the transmission is placed in a single operating lever.

Engine. The engine is a horizontal-opposed four-, six-, or eight-cylinder internal-combustion engine using crude oil or distillate as fuel and operating on the two- or four-cycle principles. The trucks have the horsepower required for the drawbar pull and tractive effort necessary for the service to be rendered. The fuel is injected into a small cup-shaped receptacle in the head of the cylinder, the high compression vaporizing and igniting it. Just before the piston reaches the end of its out, or down, stroke, the exhaust ports are uncovered and, at the same time, a valve in the head is opened to the atmosphere, the exhaust gases being drawn out through a suction fan and the muffler. The cylinder is thus completely scavenged by the fresh air admitted. The cylinders are water cooled; pipes lead from the truck through locomotive swing joints to the body and then to the radiator, which is located in the roof of the car and is cooled by an independent electric-motor driven fan. The company intends to experiment in air cooling the engine cylinders by means of enclosed aluminum fins and a forced air circulation. The engine is started by an electric motor which is connected into the multiple-unit control system described on page 88. The crankcase of the engine and the casings of the hydraulic generators comprise a unit that forms the bolster* of the truck and is spring supported, Fig. 61. Thus vibration of the engine is relieved and the same cushioning effect is provided as if the engine were inside the car body. Vibration of the car is also reduced to a minimum.

Transmission. As no flywheel is used, the crankshaft is extended at each end, on which are mounted hydraulic pressure generators, Fig. 62, consisting of common castings in which are bored nine holes, or cylinders, (only eight are shown in the sections at the right) each fitted with a piston plunger. At the outer end of each crankshaft extension is mounted a ring that is keyed to it. This ring, which is termed the *stroke regulator*, is

* Patented.

mounted on a special joint in such a manner that it can assume an angle of inclination with respect to the crankshaft and at the same time revolve with it. The ring is also connected to the pistons by means of ball-end connecting links. When the crankshaft revolves, this entire mechanism revolves with it; while the ring is at right angles to the crankshaft, no motion is transmitted to the pistons, but as soon as the stroke regulator is moved to one side or the other of the vertical center line, the pistons immediately have a stroke, and the greater the inclination of the ring the longer the stroke until the maximum is reached. The pistons which at any given instant are above the horizontal center line move in toward the center of the truck, and those which at the same instant are below move outward and cause suction. At the back of the pistons is a valve plate so constructed that half of the pistons deliver oil and pressure through it, while the other half of the pistons receive their supply from it. To the two ports in this plate are connected pipes which lead to two similar ports in the hydraulic motors on the axles and a closed circuit is thus formed.

The hydraulic motors, Fig. 62, are similar in construction to the pressure generators, with this exception, however, that in the motor the ring is fixed at a given angle and therefore the pistons have their maximum stroke at all times. The ring, or stroke regulator, on the pressure generator may be moved from its zero position to its maximum in either direction at a given rate or by a series of infinite steps, thus causing a variation in the volume of liquid pumped; this, in turn, causes a greater or less pressure against the pistons of the hydraulic motor and therefore a greater or less turning effort and speed of rotation. The oil which is used as a power-transmitting medium may be caused to flow in either direction through the pipes and the system. Since the motor has a constant stroke and the pressure generator a variable one, sufficient torque may be generated to slip the wheels under any car. As it is a well-known fact that it takes a given power to propel a given tonnage, the engine and the transmission must be proportioned according to the required drawbar pull or resistance. A small electric motor controlled through the multiple-unit control system by the master controller swings the stroke regulator about its center in either direction so as to give the desired rate of accel-

ation. The forces acting on the pressure generator are balanced out the horizontal center line, therefore only a small amount of nergy is required to overcome the frictional resistance.

To make clear the operation of this transmission, an explana-ion in connection with Fig. 63 follows. It is assumed that the ntire pressure generated by the hydraulic pressure generator is oncentrated at the center line of the axle and thus at the highest oint of inclination in reference to the horizontal center line. As ere are nine pistons in the casting, four are constantly generatg pressure, one is passing the neutral point on the horizontal nter line, and four are on the opposite side of this horizontal nter line and are causing suction. It was found that it was cessary to have an odd number of pistons in order to obtain a

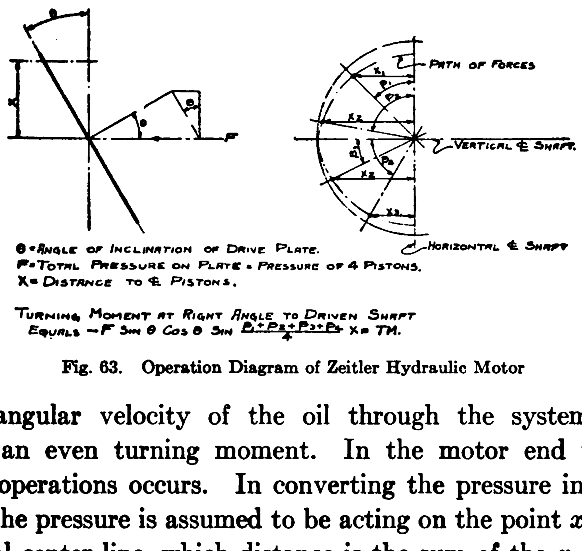


Fig. 63. Operation Diagram of Zeitler Hydraulic Motor

gular angular velocity of the oil through the system and to oduce an even turning moment. In the motor end the same cle of operations occurs. In converting the pressure into rotary otion, the pressure is assumed to be acting on the point x from the orizontal center line, which distance is the sum of the x distances. herefore, the force acting on the inclined plane is the force $\times$ sine θ $\times$ cosine θ $\times$ distance x, which gives the rotary force ting at right angles to the axle. In other words, the force is ting on an inclined plane at the average distance x from the orizontal center line.

The transmission is very simple in design, and since all parts ork in oil, they are thoroughly lubricated, which means long life id almost negligible wear. At excessive high pressures the oil

will leak past the pistons into the ring chamber, where it is caught and returned to the system again through nonreturn check valves, the suction side opening the proper check valve.

Multiple-Unit Control. The multiple-unit control is just as important to the entire system as the transmission. It was designed for a service requiring sometimes that cars be operated singly and sometimes that a number be coupled together and operated simultaneously. The motor truck and equipment furnish a system whereby any number of cars having motor trucks may be arranged in any desired relation and controlled and operated simultaneously by a single operator. The cab, which is arranged for double-end operation, contains only the controller and brake valve and may be so constructed that all the operating mechanism can be shut in when not in use and occupy very little space. A single line is so connected to a graduated voltmeter that it indicates the number of engines in a train that are running. In case one engine fails to start or run, the unit may be cut out as easily as an electric motor in an electric train. There is only one control lever and it works as follows: Advancing the control lever to the first point cuts in the engine-starting motor and simultaneously opens the fuel valve, which is controlled through an electrically driven governor. Continued advance of the controller speeds up the engine to maximum, the engine-starting motor being automatically cut out when the engine starts to run. On the end of the controller handle is a small push button having three positions, namely, normal position, or entirely out; second position, or halfway in; and third position, or all the way in. When the button is depressed completely, the acceleration motors on the hydraulic pressure generators are cut in. As long as the button is held depressed, automatic acceleration results. This acceleration may be stopped and the speed held at any point by releasing the button to the halfway position, and by entirely releasing it to its original position, deceleration is brought about and the transmission automatically returns to neutral. To reverse the car movement, an ordinary auxiliary switch is moved, reversing the direction of rotation of the acceleration motors.

Advantages of System. By the arrangement of the engine and the transmission in the truck any car—street, interurban, or

steam railroad—may be equipped. Having the entire power plant under the car and independent of it gives all the advantages of an electric car, for, in emergency or accident, a truck may be removed and replaced in an hour. The hydraulic transmission is the simplest and most direct of the power-transmitting systems and has the highest and most nearly continuous efficiency.

The wheel base of the trucks may be as short as needed for street and interurban service, and by equipping both trucks under a car the maximum tractive effort may be obtained, all the wheels being drivers, a feature of importance on slippery rails, grades, etc. The transmission in connection with the multiple-unit control system furnishes the equivalent of an infinite number of gear ratios, but without gears. This makes it possible to secure a high and smooth rate of acceleration. By reversing the hydraulic generator, it can be used as a brake in case of emergency, independently of the air or hand brakes. The lighting of the car is by means of incandescent lamps, the current being taken from the storage battery of an axle-light equipment. The system has but few parts and is free from complication. All the operating current is supplied from a 30-volt standard axle-light equipment which furnished light for the cars.

Sizes. The Zeitler* equipments† are designed in three standard sizes of engines, 200, 400, and 600 horsepower to the truck, and the trucks are generally of the M.C.B. type, such standards as are consistent being used. The 600-horsepower equipment is principally for locomotives for steam road service.

The Zeitler Company also manufactures a truck motor with a seven-speed mechanical transmission in sizes of 100 horsepower and 150 horsepower.

INTERNAL-COMBUSTION ENGINE LOCOMOTIVES

Development. The self-contained locomotive using the internal-combustion engine has not been developed up to the present time to the stage where it can compete with the steam and the electric locomotive. As is shown by the following illustrations and

* Zeitler Gas Car and Locomotive Company, 20 West Jackson Boulevard, Chicago.
† Patented.

descriptions, attempts have been made along this line, but, as was the case with the steam and the electric locomotive, there must be a number of stages of progress before the type can be perfected.

Advantages of Type. Since the internal-combustion engine can and does develop more power for a given space, or area, occupied than any other type of prime mover and since it is adapted for long and continuous service and lends itself easily to repairs and replacements, the trend is toward the operation of both passenger and freight service by this type of engine. Operation and maintenance costs are less when it is used than when either the steam or the electric locomotive is employed. More has been done in the development of this engine than the casual observer imagines. The one thing that has not been worked out to give thorough satisfaction in operation is an elastic transmission between the engine and the wheels; however, this is being rapidly developed and the near future holds the solution. Never before in the history of the United States has there been such a demand as now exists for a more economic and reliable motive power to transport the world's supplies, and this demand means a more concentrated effort to develop a locomotive of the greatest possible efficiency.

Transmission in Locomotives. An important factor in locomotive design is the arrangement of the control (transmission again), as, in a locomotive, this problem has its distinctive characteristics, for at every speed the power required can vary within wide limits owing to the changing grades, track conditions, and engine resistance. Thus, although an engine may be hauling its load at 60 miles per hour with the throttle open one-third, there may be such a change in conditions in a minute that the full power, or throttle, will be needed to maintain the same speed. It follows as a corollary to the above fact that the locomotive is not loaded to its maximum capacity, or anything like its maximum capacity, all the time during the run—a feature decidedly advantageous.

Sulzer-Diesel Locomotive. *Engine.* One of the most successful locomotives of the internal-combustion engine type is the Sulzer-Diesel, Fig. 64, designed by Dr. Diesel and using the famous Diesel crude-oil internal-combustion engine. The locomotive illustrated was constructed by Sulzer Brothers in their Winterthur

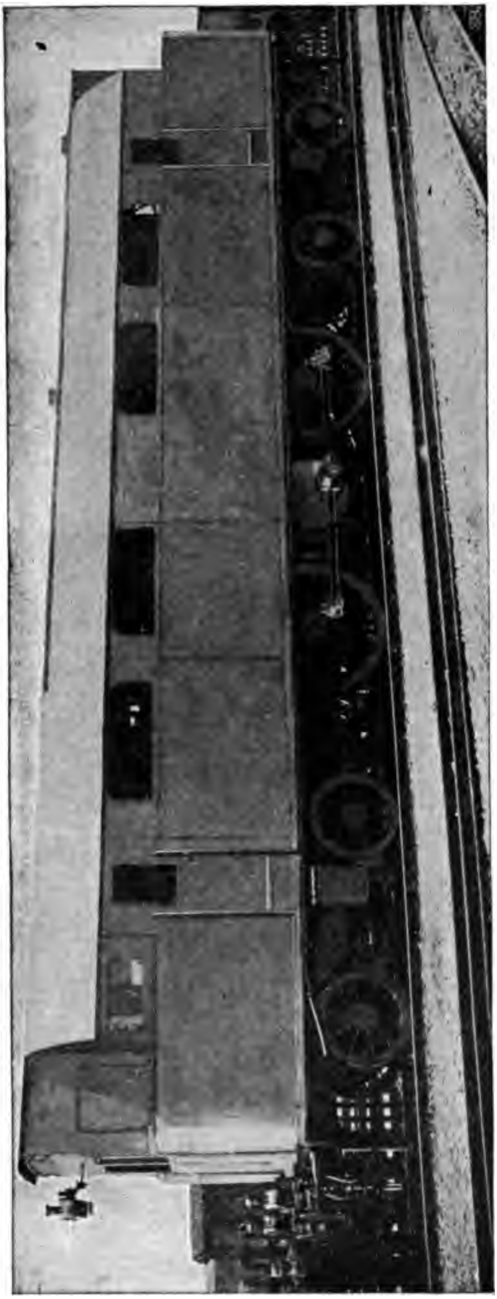
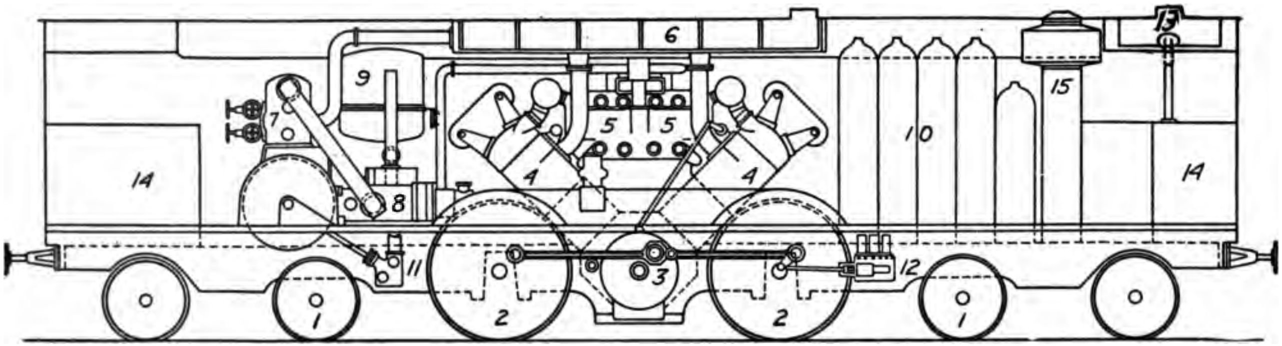


Fig. 64. Sulzer-Diesel Thermo-Locomotive



DIESEL LOCOMOTIVE

1	TRUCKS	6	MUFFLER	11	WATER PUMP
2	DRIVING WHEELS	7	AUXILLIARY ENGINE	12	WATER PUMP
3	CRANK SHAFT	8	AIR PUMPS	13	APPARATUS FOR BACK COOLING
4	DIESEL ENGINE	9	COOLER	14	TANKS FOR RESH WATER & FUEL
5	SCAVENGING PUMPS	10	AIR CYLINDERS	15	BOILER FOR HEATING TRAIN

TOTAL WEIGHT 85 TONS

Fig. 65. Arrangement of Parts of Sulzer-Diesel Power Plant

shops in Germany and is rated at 1200 horsepower. The driving unit consists of a four-cylinder single-acting two-cycle reversible engine, in which the cylinders are set at 45 degrees to the vertical in pairs on either side of the center line with 90 degrees between the opposing cylinders, Fig. 65. These are built on a crankcase fixed across the locomotive frame, and through bolts are carried in the usual way from the cylinder heads directly to the bearing webs, the cylinders themselves being relieved from the stresses arising from the pressure of the heads. The crankshaft has two throws 180 degrees apart, and each crankpin is driven by two connecting rods from opposite cylinders, the big-ends being forked to give a perfectly symmetrical disposition of the power lines. One big-end occupies the middle of the crankpin, while the other is branched to bear on the pin in the two spaces next to the crank webs. Outside the locomotive frame two disc cranks with balance weights are formed on the crankshaft to transmit the power through side and connecting rods to the wheels. In this manner a complete balance is obtained of the primary forces of the reciprocating masses in the engine and the centrifugal forces of the cranks, connecting rods, and balance weights. Counterweights are introduced in the driving wheels to neutralize the rotating masses which influence them. The secondary forces due to the obliquity of the connecting rods remain free, but since the resultant passes through the crankshaft midway between the center lines of the cylinders and is horizontal, it does not give rise to rocking effects or oscillations perpendicular to the track.

The cylinders have a bore of 380 millimeters $\left(14\frac{31}{32}\text{ inches}\right)$, Fig. 66, and a piston stroke of 550 millimeters $\left(21\frac{21}{32}\text{ inches}\right)$. At 304 r.p.m., the rate at which the engine turns when the locomotive is traveling 63 m.p.h., the maximum brake horsepower is 1600. It is rather difficult to name a power at which this type of engine should be known, but the builders employ the term "1000-horsepower thermo locomotive." In relation to its power the engine is remarkable for its compactness and occupies only one-third the length of the body. Its weight does not exceed 95 tons, and the fact that a number of air reservoirs and an auxiliary air com-

pressor set of 250 horsepower are carried shows that the material was judiciously used in its construction.

Between the four inclined cylinders are two double-acting pumps and a three-stage air compressor, the three units being

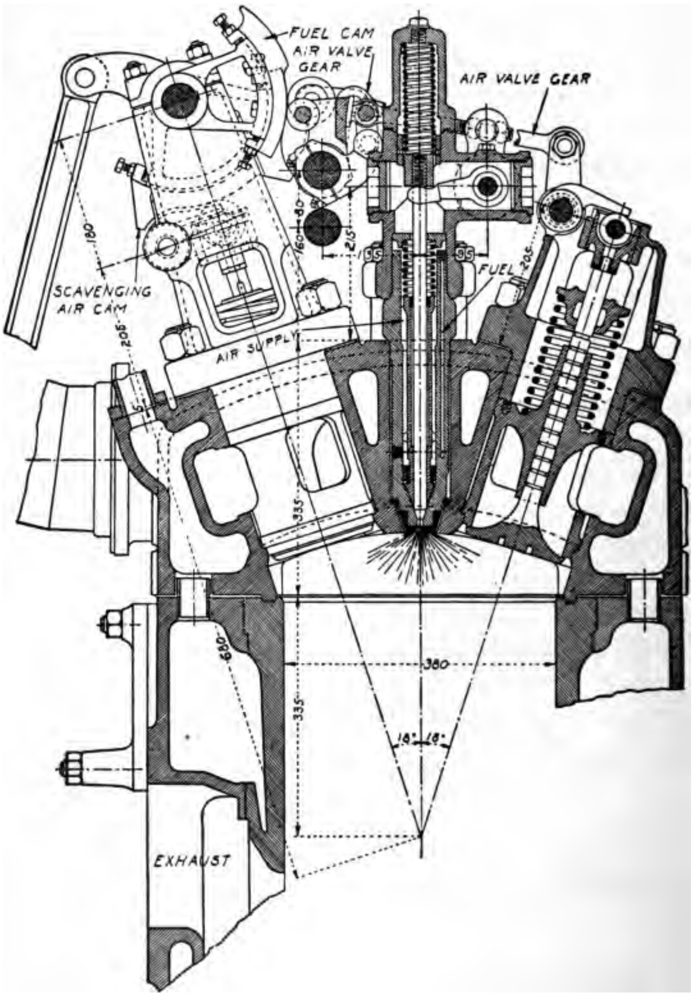


Fig. 66. Cylinder Head of Sulzer-Diesel Engine

driven from the connecting rods of the forward cylinders by means of rocking levers and links. They are all provided with safety valves. This compressor has only sufficient capacity to

furnish the injection air at reduced speeds and loads, should the 250-horsepower air compressor set for any reason not be running. Each scavenging pump supplies air to the pair of cylinders immediately next to it, the air pipes being so short that no trouble can arise in them from inertia or from surging, both of which would interfere considerably with the scavenging of a high-speed engine.

Pressure. At full power the mean indicated pressure in the engine is as high as 175 pounds per square inch, which is practically double that used in ordinary Diesel practice. Shortness is a

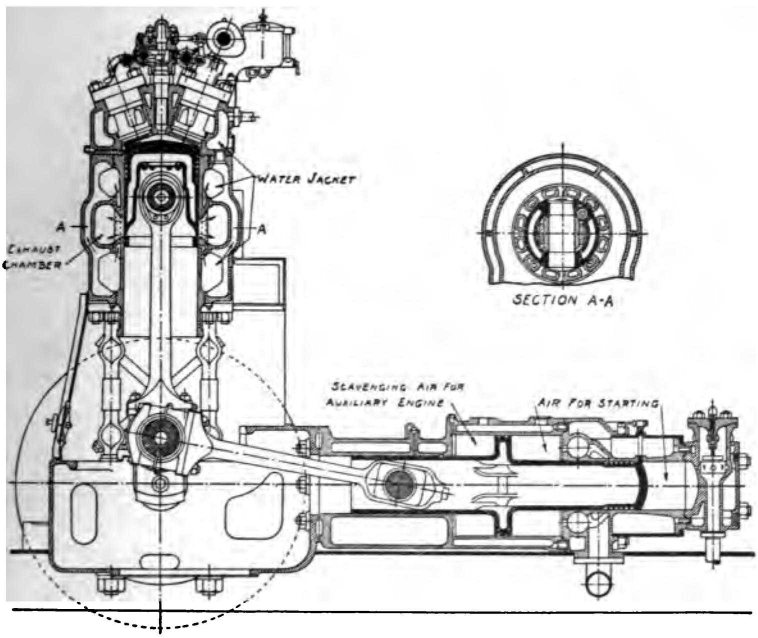


Fig. 67. Section of Sulzer-Diesel Engine, Driving Auxiliary Air Compressor Set

feature of the exhaust pipes, which lie between the cylinders and connect from the exhaust ports straight to the mufflers in the roof. Each pair of opposed cylinders exhausts into a separate manifold and then through a common third muffler into the atmosphere. The three parallel expansion chambers are subdivided by baffle plates.

Auxiliary Air Compressor Set. In the forward part of the locomotive stands the auxiliary air compressor set, consisting of a two-cylinder vertical two-cycle 250-horsepower Diesel engine, driving

two horizontal air compressors, Fig. 67. The engine cylinders have a bore of 305 millimeters $\left(12\frac{1}{64}\text{ inches}\right)$ and a stroke of 380 millimeters $\left(14\frac{31}{32}\text{ inches}\right)$ with two cranks set at 180 degrees. In this engine the scavenging is effected through two valves in the head of each cylinder, the exhaust being blown through ports uncovered by the pistons at the bottom of the stroke. In the usual Sulzer manner, the cylinder heads are bolted straight through to the bedplate and diagonal ties are used. The crankcase is enclosed, forced lubrication being employed for the main bearings and the ends of the connecting rods. Separate oil pumps supply the lubrication to the cylinder walls, the quantity delivered at each feed being adjustable.

Valves. In the cab at each end of the locomotive there is a starting valve with two levers, through one of which the main engine is connected to the air reservoirs, while the other controls the blast to the engine. Although, owing to the particular regulation of the various valves, the main engine can be worked at an exceedingly heavy duty, its operation on the whole is similar to that of the usual Diesel type. Fig. 67 illustrates the cylinder head in section, showing the two scavenging valves and the fuel injector. An important feature is the relative high pressure of the scavenging air, this being supplied to the cylinders at 21 pounds per square inch. The starting air is admitted at 750 pounds per square inch and the blast varies between 750 and 1050 pounds per square inch. All these valves are subject to variation of timing, the operation of each being regulated to suit the load on the engine.

Starting and Stopping Locomotive. To start the locomotive, the auxiliary air compressor set being at work and the starting gear in the most advanced position, air is admitted gradually to the main cylinders by a progressive movement of the valve on the starting reservoirs. As the pressure in the cylinders rises, the engine gets under way and turns the driving wheels. As the speed of the locomotive increases, the starting mechanism is notched back slightly and at 6½ m.p.h. it is thrown out entirely and the fuel valves cut in. The locomotive is then working under normal

conditions and, according to the power and speed required, the fuel injections and blast pressure are regulated in the manner previously described. To bring the train to rest, the fuel supply is cut off and the brakes applied. The air for the brakes is taken from the intermediate stage of the air compressor and supplies the brake cylinders through special reservoirs. Reversing is accomplished from either end of the locomotive by turning the wheel which operates the reverse rods and interlocks the fuel valves with them.

Pumps. Four auxiliary pumps are installed, of which two are driven from the auxiliary engine and two are operated by the connecting rods. Three of these pumps are connected with the water circulation and the fourth maintains the fuel supply to the engines. The main circulation pumps feed the water from the different circuits to condensers in the roofs over the cabs. The rate of flow can be regulated; in order to prevent the water flowing from the condenser too quickly, its outlet is restricted, four small pipes leading to the reservoir below, where it is drawn off by the circulation pump. The supply for the piston cooling is taken from the pressure side of the main pumps and is delivered by a separate pump. A cold-water pump is available, and into this is built a small pump which pushes fuel from the main tanks through a filter to the injection pumps on the engine, the overflow returning to the tanks. In the cab four rotary pumps are installed, one for cold water, one for the circulation system, and one for the fuel supply, the purpose of the three being to prime the pipes. The fourth is connected with the forced lubrication of the main engine in order that the bearings inside the crank chamber may be lubricated before starting the engine. On both sides of the locomotive the water piping is brought together in order that the water spaces may be drained when so required.

Miscellaneous Description. At each end of the locomotive is a cab for the engineer, who has under his control the various levers, such as one for the starting fuel valves and one for the fuel injection pumps, a wheel for the starting air supply, the brake lever, the sand blast, and the different gages. The locomotive is 54 feet 5½ inches over the end buffers and has a rigid wheel base of 11 feet 9½ inches. The entire driving mechanism is enclosed in

dirt- and dust-proof housings, doors being provided to give easy access for inspection. In the corners of the cabs are reservoirs for air, water, and fuel. There are three longitudinal divisions in the roof, two spaces being used for the air supply to the different compressors and air pumps, all of which are supplied from separate pipes. The central division is occupied by the mufflers, but at the ends over the cabs are, respectively, a condenser and a honeycomb radiator.

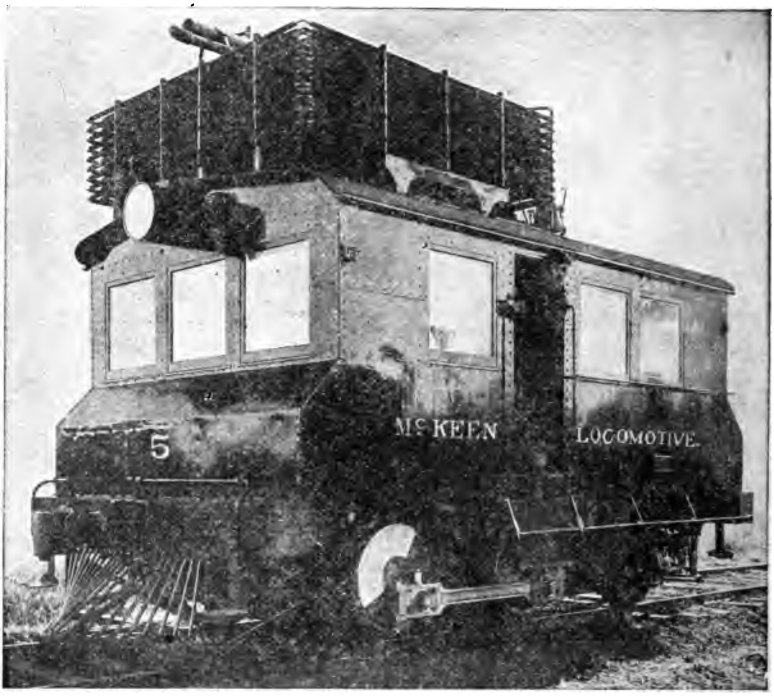


Fig. 68. McKeen Gasoline Switching Locomotive

McKeen Locomotive. *General Description.* The McKeen gasoline switching and freight locomotive, Figs. 68 and 69, is manufactured by the McKeen Motor Car Company, Omaha, Nebraska, and has a tractive effort of 12,000 pounds at 6 m.p.h. It is mounted on six 42-inch wheels, four of which are driven by a six-cylinder type C gasoline engine, the wheel arrangement being of the 042 class. The frames are of cast steel, and the cab is an all-steel built-up structure extending the entire length of the locomo-

tive between the bumper beams and is so bolted to the frames and the bumper beams as to add very materially to the strength of the locomotive. The usual type of locomotive spring suspension with equalizers is used to transfer the weight to the wheels. The engine bed is a steel casting which forms an efficient brace and reinforcement in tying one side frame to the other. In the 300-horsepower six-cylinder engine the diameter and stroke are 11 inches and 15 inches, respectively. Its general design and details

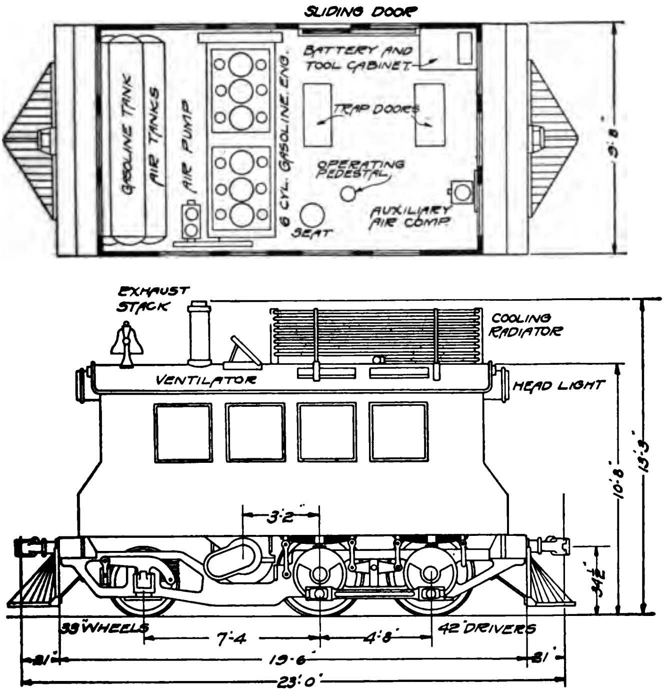


Fig. 69. Arrangement of Equipment in McKeen Gasoline Locomotive

correspond to the manufacturer's latest model "Foolproof" engine, which is provided with increased water circulation around the valves and cylinder heads, tungsten steel valves, triple piston rings, water-jacketed intake pipes, enclosed flywheel, crankshaft, water- and air-pump mechanism, combination splash, and an automatic lubricating system.

Two exhaust pipes are provided which extend above the roof. The engine has an air reversing mechanism which slides the cam-

shaft for reversing the direction of rotation of the engine, the camshaft being provided with two sets of cams. Two 5-inch air compressors are attached to the engine crankshaft, in addition to an auxiliary compressor, as described under the McKeen Gasoline Motor Car, page 30.

Transmission. The ends of the front or main axles and the rear driving axles have counterbalanced crank discs which are connected by side rods. The transmission is pneumatically operated and power is transferred by a sprocket on the crankshaft and a Morse silent chain to a sprocket on a sleeve working free on the rear driving axle and then by a Morse chain to the forward axle,

Fig. 70. Baldwin Industrial Gasoline Locomotive

where, by another clutch, it is either magnified by a series of herringbone gears to produce a heavy tractive effort and high torque for starting and heavy loads or is delivered direct to the driving wheels. By thus magnifying the torque of the internal-combustion engine, great starting effort is attained in this type of locomotive. At the same time, when the locomotive is once in motion, higher economy is obtained by cutting out the gears and operating on a direct connection.

Engineer's Position. The engineer's position is at the center and on the right-hand side with an uninterrupted view in all directions. All levers for operating, including the air-brake valve and reverse control, are at his side. In this type of locomotive signal

observation is superior to that of the steam locomotive on account of the absence of the boiler and the tender.

Baldwin Gasoline Locomotive. The Baldwin Locomotive Company, at Philadelphia, Pennsylvania, build small industrial gasoline locomotives. The largest locomotive of this type constructed by this company was built for a cereal plant at Battle Creek, Michigan, and is on the same general lines as the smaller ones. This locomotive, Fig. 70, was designed for standard gage, having a vertical four-cylinder four-cycle engine, which gives a drawbar pull of 6000 pounds on low gear and 1700 pounds on high gear. The frame is mounted on 42-inch driving wheels and has a rigid wheel base of 6 feet 6 inches, a total length of 19 feet 4 inches, a height of 11 feet from the top of the rail to the

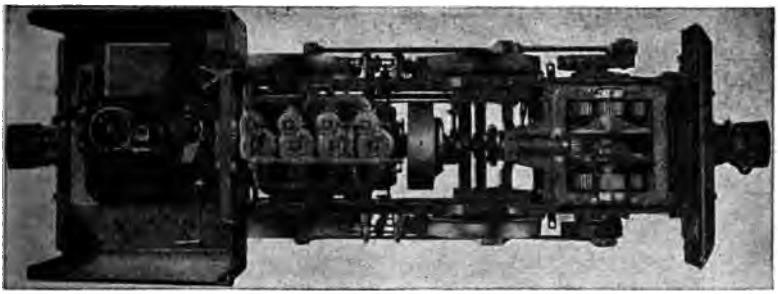


Fig. 71. Plan View of Baldwin Gasoline Locomotive, Showing Arrangement of Parts

top of the cab, and an over-all width of 9 feet. The locomotive was designed to haul 200 tons on level track and around 28-degree curves or lighter loads up various grades. The consumption of gasoline in average service was found to be about 4½ gallons per hour hauling 80 tons back and forth over level track and 8 per cent grades.

Operation. The gasoline engine, Fig. 71, drives a bevel pinion through the friction clutch in the flywheel, which pinion is constantly in mesh with two large bevel gears on the intermediate shaft. With the main clutch in the flywheel engaged, the large bevels revolve in opposite directions. These bevels run loose on the intermediate shaft, except when one or the other is engaged by a forward and reverse jaw clutch which is located between the bevels and provides for the operation of the locomotive in either

direction. Two spur gears of different diameters are keyed on the intermediate shaft and are constantly in mesh with corresponding high- and low-speed gears on the countershaft directly under the intermediate shaft. The two countershaft gears run loose except when one or the other is engaged by a high- and low-speed jaw clutch located between them. On this same shaft are two driving discs set 90 degrees apart and connected to both pairs of driving wheels by Scotch yoke side rods. Only one side rod is used on each side, which method ensures a positive drive and yet allows free vertical motion of the driving wheels and complete spring suspension of the entire locomotive. The design has been developed from steam practice, as is evident in the illustrations.

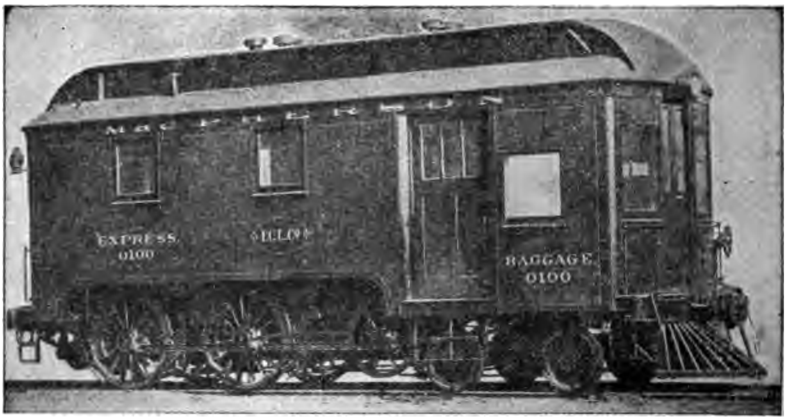


Fig. 72. 20-Ton Gasoline Locomotive

The imitation smokestack is the muffler. The motor is water cooled and especially designed for the service requirements. The parts of the engine and the transmission are thoroughly lubricated and run in oil-tight casings.

Internal-Combustion Engine Locomotive. The Internal-Combustion Engine Locomotive Company, of Wilmington, Delaware, brought out, in 1915, an internal-combustion engine locomotive for double-end operation similar in general arrangement to the regulation steam locomotive, with side connecting rods, drivers and frame, and pony leading truck to negotiate sharp curves, Figs. 72 and 73. The transmission is of the mechanical drive type and has a master clutch of the Hele-Shaw multiple-

disc type connecting the engine and the driving shaft with the transmission system. The driven shaft of the transmission carries an individual clutch for each speed to be applied, thus giving a transmission without gears to slide in and out of mesh. The transmission differs from the automobile form in having the same number of running speeds in either direction. The application of the power by this transmission is through chain and sprocket, although gears constantly in mesh may be substituted. The fuel is gasoline, kerosene, ozoline, or distillates. The heating and lighting of the trailing coaches are provided by the locomotive

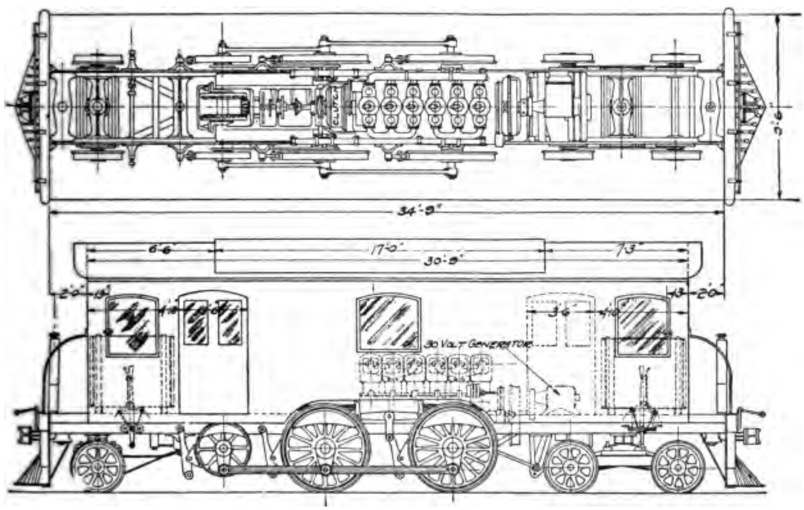


Fig. 73. Arrangement of Equipment in Internal-Combustion Engine Locomotive

which is capable of hauling trains at a speed of from 25 to 50 m.p.h.

General Electric Locomotive. The gas-electric locomotive illustrated in Figs. 74 and 75 was built by the General Electric Company, Schenectady, New York, and is used by the Minneapolis, St. Paul, Rochester and Dubuque Electric Traction Company, operating what is popularly known as the "Dan Patch" electric line, which is said to be the first railroad operating entirely with an internal-combustion engine service. This 60-ton locomotive is double ended, being built with the box type of cab extending nearly the entire length of the underframe and having all the

weight on the drivers. The wheels are 33 inches in diameter, each truck being equipped with 100-horsepower motors. The truck clearances allow for a 100-foot minimum radius of track curvature.

Power Plant. The power plant consists of two 135-kilowatt generating plants similar to the ones used in the gas-electric motor cars and one engineer is required for its operation. Each of the two gas-electric generating plants is composed of a 175-horsepower, 550-r.p.m., eight-cylinder four-cycle gasoline engine of the V type direct connected to a 600-volt commutating-pole, compound-wound electric generator, with an outboard bearing supported by brackets bolted to the magnet frame. The cylinders have an

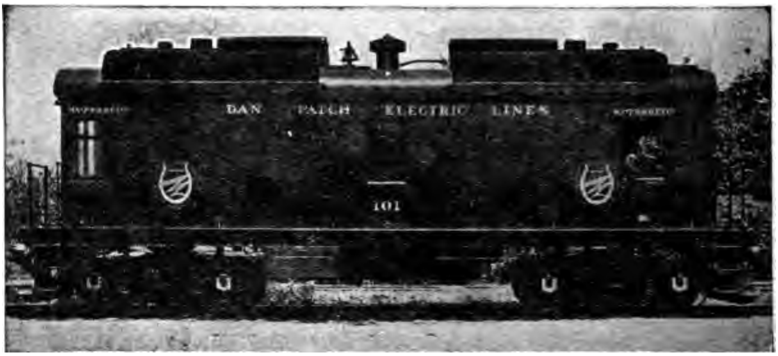


Fig. 74. 60-Ton Gas-Electric Locomotive Used on "Dan Patch" Lines

8-inch bore and a 10-inch stroke. Ignition is by a low-tension magneto. The engines are started by compressed air in the same way as on the gas-electric cars, with the additional feature that after the first one is running the second may be started electrically from it. The control is arranged so that one or both generating sets may be used to operate the locomotive from either end in accordance with the trailing load. Compressed air for starting is taken from the main reservoirs of the air-brake system, these being built with a surplus capacity. The two single-cylinder air compressors which are driven from the crankshafts of the main engines have a displacement of 22½ cubic feet of free air per minute at the rated speeds and are fitted with automatic governors to maintain a constant pressure.

The engines can rotate at normal speed irrespective of the speed of the locomotive and deliver their maximum power at all times,

a feature of advantage on grades, in case of storm, or under other emergency conditions involving sudden heavy current demands.

Auxiliary Power Plant. The locomotive is provided with an auxiliary gas-electric set to furnish power for lighting the cab, headlights, and trailers and for pumping an initial charge of air to fill the reservoirs and start the engines. This set is started by hand and consists of a vertical four-cylinder four-cycle 750-r.p.m. gasoline engine which is direct connected to a 5-kilowatt 65-volt commutating-pole compound-wound electric generator. The cylinders have a 3-inch bore with a 6-inch stroke, and ignition is by a high-tension magneto. The air compressor on the 65-volt circuit is of the two-cylinder railway type and has a displacement of 25 cubic feet per minute against a tank pressure of 90 pounds per square inch.

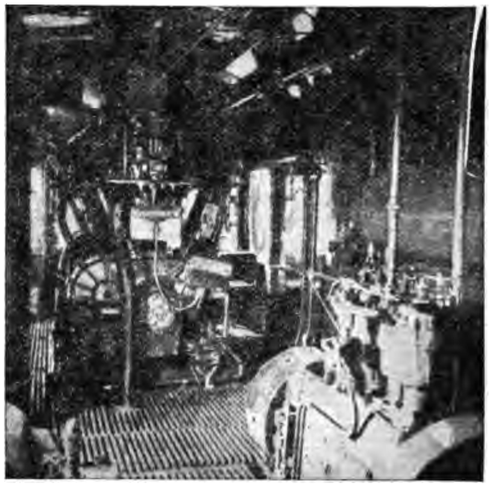


Fig. 75. Cab Interior of "Dan Patch" Line Locomotive

Air for all the compressors is taken from the cab interior through screens and delivered to the three reservoirs, each 18 inches by 87½ inches, which are installed at one side of the cab in the center and are connected in series, thereby affording an opportunity for the radiation of heat and the condensation of moisture before the air enters the air-brake cylinders. After starting the main engines, the governor cuts out the motor-driven set and all air is supplied by the air compressors on the main engines.

Tractive Effort. Mounted on the axles with nose suspension are four General Electric 205D 600-volt commutating-pole series-wound box-frame railway motors, having an hourly rating of 100 horsepower each. All four axles are, therefore, driving axles. The gear ratio is 17:58 (a reduction of 3.41), which ratio is especially adapted for freight and switching service as it affords a maximum

tractive effort for starting and low speeds. The motors are ventilated by a special vacuum system operated in conjunction with the engines. The performance of the locomotive is approximately such that a tractive effort of 16,000 pounds is provided at 5 m.p.h. and 3500 pounds at 30 m.p.h.

Control of Motor Equipment. The control of the motor equipment is similar to that of the standard gas-electric motor car, with the cab installed at each end. The motors, however, are connected permanently in pairs in parallel, and the two pairs, operating like single motors, are placed progressively in series and parallel. The controller provides seven running steps in series and six in parallel without rheostats in the main circuit. There are two additional points for shunting the fields, making a total of fifteen running points.

To produce smooth and rapid acceleration, the speed changes are made by governing the voltage through varying the strength of the generator fields, this being accomplished by the movement of one handle on the controller. Separate handles are provided for throttling the engine and reversing the motors. The latter operation is accomplished by changing the motor connections in the usual manner and without stopping the engines which always rotate in the same direction. This, in an emergency, allows the train to be brought quickly to a stop independently of the brakes.

Construction Data. A 300-gallon gasoline tank fitted with cap and filler is installed beneath the underframing of the locomotive. The radiators are of the fin type and are mounted on each section of the cab roof, the water being circulated by the thermosiphon system. There is also a radiator draining system, the tanks being situated at one side in the central section of the cab; and a suction type of ventilator is mounted in the roof between the radiators.

The principal data and dimensions are as follows:

Total net weight	120000 pounds
Weight, per axle	30000 pounds
Maximum tractive effort	32200 pounds
Length between couple faces	42 feet 4 inches
Length over cab	34 feet
Height over all	14 feet 10¾ inches
Width over all	10 feet 2 inches
Total wheel base	24 feet
Rigid wheel base	6 feet 10 inches

Zeitler Gas-Hydraulic Locomotive. Many of the features to be embodied in the design of an ideal internal-combustion engine locomotive depend entirely upon the point of view. Any locomotive, however, must contain certain essential features, namely:

(1) Mechanical parts of strength sufficient to meet the service
(2) Sufficient engine capacity to develop the required power
(3) A reliable transmission between the engine and the wheels
(4) A complete control system
(5) Riding qualities that enable the locomotive to negotiate the rails without undue damage
(6) Weight on the driving wheels sufficient for adhesion

The Zeitler gas-hydraulic locomotive, Fig. 76, is intended for both freight and passenger service. The general design of the trucks, the engine, and the transmission is similar to that designed and used for independent passenger car service, with the exception that the trucks have cast-steel side frames which are so constructed that by removing part of the wheel piece, the entire engine may be removed for repairs or renewals. The engine for the locomotive is either a six- or eight-cylinder two-cycle crude-oil or distillate burning type and is of high-speed construction, developing a maximum horsepower of 400 or 600.

Power Plant. The engine is started by an electric motor deriving its current from the storage battery and coupled into the control system, so that no special switch is used for starting the engine, all the starting being accomplished through the master controller handle. This motor is cut out automatically when the engine starts to run. All the machinery with the exception of the air compressor, is mounted entirely on the trucks, which makes it possible to utilize the interior of the locomotive for other purposes. The air compressor is direct connected to a separate engine and with this engine constitutes an individual unit, thus making it possible to supply air to the main reservoirs without starting the main engine.

Hydraulic Transmission. The hydraulic transmission is the same as that used on the Zeitler independent motor cars, page 85, and is proportioned to the service requirements. No gears are used, since the transmission is direct connected to the axles, and the losses caused by the gears are thus eliminated. Smooth and even acceleration is obtained and the transmission may be put in

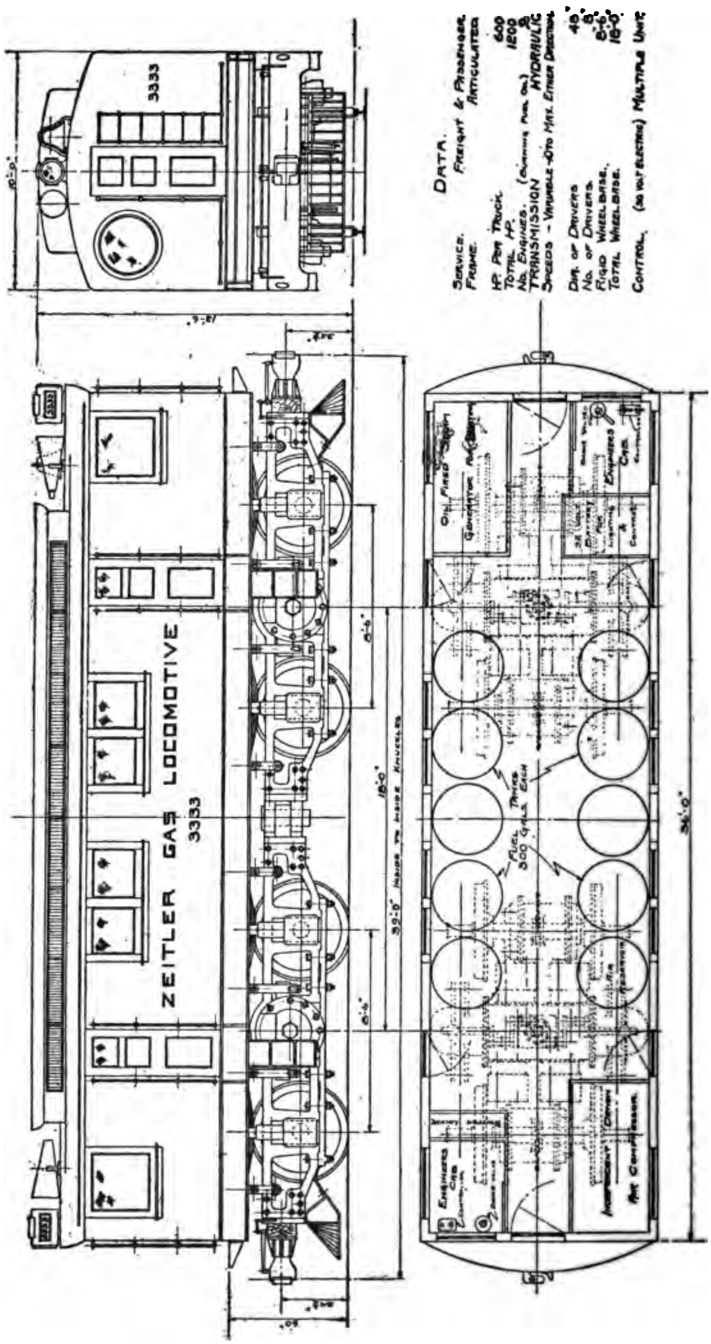


Fig. 76. Arrangement of Equipment on Zeitler Gas-Hydraulic Locomotive

such a low-speed ratio as to slip the wheels, if the resistance is great enough. The engines may be run at a constant speed or at a variable speed to suit the condition of the load. In case of emergency, the hydraulic transmission may be reversed and used as a brake independently of the air or hand brakes. In fact, after some practice, the hydraulic transmission may be used for general braking and thereby save air.

Radiators. The radiators are placed in the roof of the locomotive, one for each engine, and are cooled by a forced-air circulation. The fan for this purpose is driven independently of the engine by a 30-volt electric motor and is connected in with the control system so that its speed is regulated according to the engine speed.

Characteristics of Type. By means of the multiple-unit control system two or more locomotives may be coupled together and operated as a single unit, thus providing the necessary tractive effort for heavy loads. As this locomotive is provided with double-end control, no switch is required at terminals, and as the speed and pull may be varied within wide limits, the locomotive may be used for either freight or passenger service. However, its use for passenger service depends upon whether or not it is so designed that it can hold the rails at high speeds. The body of the locomotive is, in general, similar to that used for electric locomotives, but may be varied to suit the requirements of the purchaser.

CRUDE-OIL BURNING GAS ENGINES

Importance of Type. Owing primarily to the expiration of the basic Diesel patents, the recent development of the crude-oil burning prime mover has been unparalleled and its application to marine work has been especially noticeable. The marine interests of this country have watched closely the work of this engine and today it is an accepted power in that field. Other applications of it are common and Diesel engines, Fig. 77, or closely related types are found in all lines of work.

DIESEL ENGINE

Definition. In spite of the fact that the name Diesel has spread over the entire world but few engineers have ever tal

the time to study thoroughly the movement of the engine and to learn of its practical application and uses in the engineering world. This type of engine may be defined in a few words as follows: an internal-combustion engine which takes crude oil or the residue

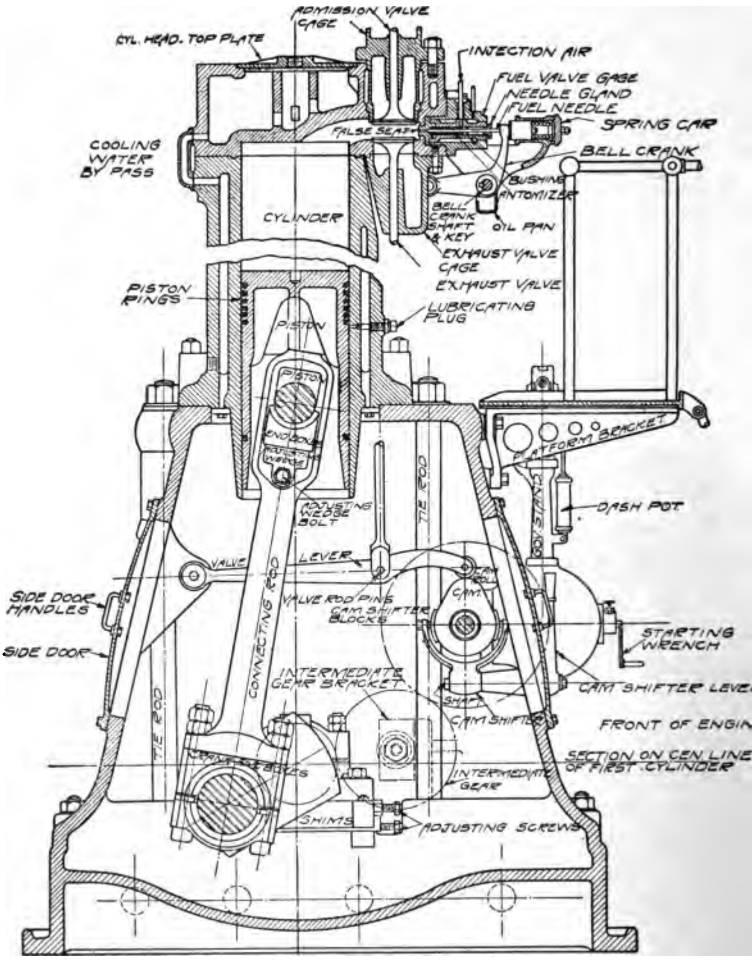


Fig. 77. Section of Typical Diesel Engine

from oil refining into the cylinders without any previous transforming, and there converts it into energy, exerting that energy directly on the crankshaft through the pistons without any intermediaries and producing the simplest, most direct, and most economical operation.

Cycle of Operations. The cycle of operations of the four-cycle Diesel engine is as follows:

Stroke 1, Admission. The piston travels down, or out, allowing the cylinder to fill with pure fresh air from the inlet valves.

Stroke 2, Compression. The piston travels up, or in, compressing the air in the cylinder. The compression heats the air so much that the oil discharged into it will ignite and burn.

Stroke 3, Combustion. The piston travels down, or out. At the beginning of the stroke, when the crank is on dead center, the fuel valve opens and the fuel charge, separately compressed by a small compressor, is sprayed into the heated air. The spraying extends over 12 per cent of the working stroke of the piston and the combustion is gradual, the resulting pressures being even and sustained, not explosive.

Stroke 4, Exhausting. When the piston reaches the lower, or outer, end of the cylinder on stroke 3, the exhaust valve is opened, the pressure relieved, and the piston travels up, or in, driving the exhaust gases of combustion out.

Advantages. Owing to the steady application of its power, the lack of vibration, comparative noiselessness, reliability, and small space occupied, the Diesel engine is almost ideal.

TWO-CYCLE ENGINE

Relation to Diesel. The type of internal-combustion engine working on the two-cycle principle and burning the same fuels as the Diesel will undoubtedly in the future be used for all railroad service. Fuel can be obtained practically any place and the economies of such an engine are so great that the gasoline engine cannot compete with it. In simplifying the Diesel engine, designers have long looked toward the two-cycle type because it avoids the multiplicity of mechanism used in the regular Diesel engine; however, great credit must be given Dr. Diesel for having beaten the path. The two-cycle crude-oil burning engine occupies the field far more than the layman or the average engineer knows. A large engine builder at Le Creusot, France, adopted the two-cycle type in 1914 to the exclusion of all others. The engine made by this concern has valves in the combustion chamber for starting purposes, but there is a general trend toward port inlet and exhaust; the latter is now general and the former is gaining in prominence with alert and progressive firms who realize the inherent defects of valves exposed to high temperatures. Another important phase of the two-cycle engine is crankcase compression, as it is simple and efficient. It has come into pronounced use in

Great Britain, Sweden, and Denmark in the semi-Diesel engines. This type is a modification of the crude-oil four-cycle engine based on the Day patents. While this is a simple form of prime mover, it has never been developed and has acquired a bad reputation, largely because in building it manufacturers have followed common practice instead of eliminating flagrant defects in design.

Nordberg Oil Engine. An oil engine of the single-acting two-cycle type is manufactured by the Nordberg Maufacturing Company, of Milwaukee, Wisconsin, Fig. 78. While this engine is

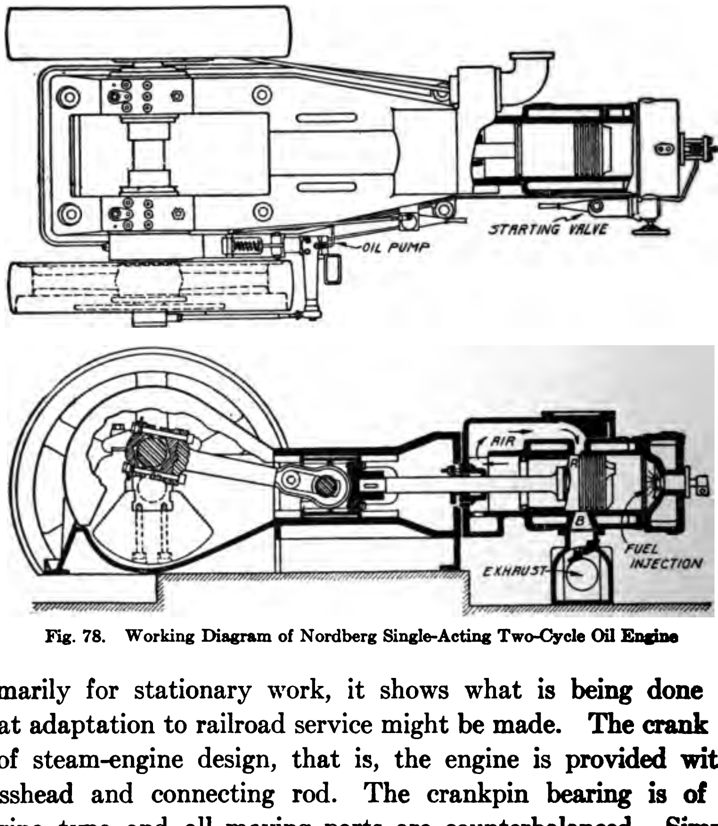


Fig. 78. Working Diagram of Nordberg Single-Acting Two-Cycle Oil Engine

primarily for stationary work, it shows what is being done and what adaptation to railroad service might be made. The crank end is of steam-engine design, that is, the engine is provided with a crosshead and connecting rod. The crankpin bearing is of the marine type and all moving parts are counterbalanced. Simplicity is the keynote of the design, there being no valves except one for admitting the scavenging air, so that the usual valve gear is lacking. Ignition is effected by the heat of compression and the fuel supply is controlled through a governor. The clearance space

is almost hemispherical and the cylinder and the cylinder head are thoroughly water jacketed. As shown in the illustration, the crank end of the cylinder is enclosed and a stuffing box is provided for the piston rod. Air for scavenging is drawn into the crank case space on the back stroke of the piston through a piston valve mechanically operated by an eccentric on the main shaft. Mechanical control permits a later closing of the valve, so that more air will be drawn in by the piston. On the forward stroke this air is compressed and is admitted to the combustion chamber through the by-pass over the top of the cylinder when the piston uncovers the transfer port at *A*. The volume of air admitted through the by-pass may be varied slightly to obtain the desired pressure. When the port is uncovered the air sweeps into the cylinder and is deflected so that it forces the burned gases through the exhaust port *B* at the bottom of the cylinder. On the return stroke the fresh air remaining is compressed to about 450 pounds per square inch. Near the end of this stroke a quantity of oil, determined by the governor, is injected by a pump through a fine nozzle and distributing device into the cylinder. The pump, which is of the plunger type, has a constant stroke and therefore draws in the same quantity of oil on each stroke. During discharge, however, part of the oil is returned to the suction through a by-pass valve, its opening being determined by the governor. On the pressure stroke the pump is positively driven by the eccentric on the main shaft and a cam which comes in contact with the plunger, the return stroke being accomplished by a spring.

Fuel Economy. The fact that combustion is very complete and perfect is proved by the low fuel consumption. Although primarily designed for kerosene, the Nordberg oil engine was later adapted for use with various kinds of fuel, especially crude oil. It consumes between 0.48 and 0.55 pound of oil, which has a heat value of about 20,000 B.t.u., per brake horsepower hour. The low fuel consumption shows that this engine is a compromise between the low-pressure oil engine, for instance, the hot-bulb and the high-pressure type represented by the Diesel.

Compression. As is usual in gas-engine practice, fuel economy has been obtained by raising the compression. In order to avoid the premature ignition that inevitably occurs if the mixture is

compressed beyond a rather low limit, air alone is compressed and the fuel is injected at such a time that the ignition comes at the proper moment. How to secure ignition at exactly the right instant is the most important problem to be solved in a high-compression gas engine. The complicated and expensive, though effective, means by which it has been solved in the Diesel engine has already been described. In order to secure prompt and regular ignition, the compression of the two-cycle engine must be pretty high, the pressures ranging from 390 to 520 pounds per square inch. The ultimate pressures depend not only upon the ratios of the cylinder volumes at the beginning and the end of the stroke but also upon the temperature and amount of air drawn into the cylinder, the temperature of the cylinder walls, the efficiency of the cooling system, and some other factors that cannot be exactly determined beforehand. Taking into account the average values of these unknown factors, the ratio of compression must be chosen between $\frac{1}{13}$ and $\frac{1}{16}$, that is, the contents of the combustion chamber must be from $\frac{1}{13}$ to $\frac{1}{16}$ of the total volume of the cylinder when the piston is at the bottom of its stroke.

Advantages. It will be seen from Fig. 78 that surprisingly simple construction is employed for the two-cycle crude-oil burning internal-combustion engine. In consequence an engine of this type may be produced at low cost and, owing to its great simplicity, the maintenance is low; altogether it is an inexpensive and reliable source of power.

The author believes that the solution of the problem of the use of the internal-combustion engine for railway service in the self-contained motor car and locomotive will be found along the two-cycle lines. The development of that type would be more rapid if the desire for extreme simplicity (which is not found on steam locomotives) were eliminated and as much thought were directed to the two-cycle engine as has been given to the four-cycle engine.

OPERATING STATISTICS

As the financial factor is the governing one in inducing railroads and all transportation companies to use and operate a certain type of motor cars and locomotives, a comparison of the

first cost, operating expenses, etc., of self-contained motor cars and locomotives and of other types is very essential. In any comparison of operating expenses of different types of rolling stock or motive power the greatest problem is *to equate the unequal factors, or to establish comparable services with the same volume of traffic under the same conditions and with the same earning capacity.* As the volume of traffic is a variable quantity and is stimulated or retarded to a considerable extent by the type of motive power used, it can readily be seen that this comparison must be very carefully worked out; for example, under most conditions the self-propelled railway motor car will stimulate more new business than either electric traction or steam service. However, there are still conditions, especially on long distances, where the steam service will handle the passenger traffic more successfully.

The cost of constructing and equipping a new 22-mile line for electric or gas operation is given in the following tabulation. Track construction is necessary in both cases and its cost is a variable quantity (depending upon the cost of right of way, cuts and fills, bridges, stations, and local requirements) but is the same whether the line is electrically operated or gas operated. Therefore this item is omitted in the total estimate.

	600-Volt High-Tension Electric Installation	Gas Cars
2 motor cars	$ 24000.00	$38000.00
Trolley, transmission, and feeder lines at $3500 per mile	77000.00	....
Rail bonding at $450 per mile	9900.00	....
2 substations at $24000 each	48000.00	....
Power house at $3000 per mile of track	66000.00	....
Total investment	$224900.00	$38000.00
Interest at 5% per year on investment	11245.00	1900.00
Interest per car mile based on yearly mileage of 128480	0.0875	0.0148
Saving in first investment		186900.00
Saving in interest by installing gas motor cars..		9345.00
Saving in interest per car mile by installing gas motor cars		0.0727

These figures were taken from actual service in 1914, and where comparisons are made today they should be in accordance with present prices. The cost of the electric system was obtained

from the *Engineering News* and the *Electric Railway Journal* of the same date, in which elaborate detail estimates covering the cost of 600-volt, 1200-volt, and single-phase electric lines and the cost of electric cars were given. The cost of 600-volt sixty-passenger cars was given at $12,000 to $16,000 each, but for the comparative figures $12,000 was used.

The gasoline railway motor car averages 3 miles per gallon of gasoline but some cars do better, the number of miles varying according to the weight, speed, and horsepower of the car. The cost of operation of a 200-horsepower motor car per car mile when the motorman is paid $125 per month and the conductor $100 per month, assuming a car mileage of 150 per day is as follows:

	Cost per Car mile
Fuel	4.4 cents
Oil and waste	0.45 cents
Cleaning	0.99 cents
Repairs	2.7 cents
Miscellaneous supplies	0.37 cents
Crew	4.2 cents
Total cost	13.11 cents

Running and shop repairs average 2 to 3 cents per car mile. With the large and ample proportions of the engines placed in these cars, which increase the life of the cars, a cost of operation per car mile of 16 cents is a conservative estimate for the gasoline car.

Recent reports in electrical engineering magazines have shown the operative cost of the modern and up-to-date electric interurban lines in Indiana, Ohio, and Illinois to vary from 19.4 to 20.8 cents per car mile. These lines have the most efficient power plants, serve large cities, and give frequent service; therefore, the cost per car mile is less than on short lines. In an article published in one of the electrical journals an electrical engineer gives the detail cost of operation of electric cars and shows the cost of operation and maintenance of substations to vary from $2000 to $5000 per year and the cost of maintenance of transmission, trolley, and feeder lines to be from $125 to $250 per mile per year. Figuring the cost of electric power at 1½ cents per kilowatt hour, which is conservative, and using the lowest

figure for maintenance, transmission, and feeder lines, the cost per car mile of operating an electric car would be approximately 20 cents. In this connection it is interesting to note that the report of the Railroad Commission shows that the average cost of operating electric trolley roads in the State of Massachusetts, including city lines giving frequent service, is 17.8 cents per car mile excluding interest and depreciation and 30.527 cents per car mile with interest and depreciation. Therefore, taking an average cost of operation of 16 cents per car mile for the gas motor car and 20 cents for the electric, we have the following comparison, figuring that each car will make four round trips per day, or 176 miles per day and 128,480 miles in a year.

	Electric	Gas Car
Cost of operation per car mile	20.0 cents	16.0 cents
Interest on investment per car mile	8.75 cents	1.48 cents
Depreciation per car mile	9.7 cents	1.58 cents
Total cost	38.45 cents	19.06 cents

The figures just given show a saving in favor of the gas car of 19.39 cents per car mile, and this saving in operation per car mile by installing the gas motor car in place of the electric car would mean a yearly saving, based on the yearly car mileage of 128,480 of $24,912. Therefore the gas motor cars would soon pay for themselves.

The operating statistics of the gas car as compared with those of the steam lines would show an even greater saving, since so far the electric car has shown a saving over the steam locomotive. As railroad statistics of operation are based on the ton mile instead of the car mile, it is rather difficult to make a comparison between gas cars and steam locomotives. It must be remembered that the steam locomotive usually handles a large train and that any direct comparison against it would be erroneous; therefore the comparison must be equated to meet the immediate conditions of traffic and service.

The following statistics as tabulated are actual and represent conditions as they exist in reference to the operating costs of the individual gas motor car, or self-contained motor car.

It should be noted that cost per mile for operators is not included in the cost of operation with the Hall-Scott equipment,

HALL-SCOTT TYPE M-6 GASOLINE RAILWAY MOTOR CAR

HOLTON INTERURBAN RAILROAD, EL CENTRO, CALIFORNIA

For six months ending April, 1914

Motor Car No. 5	1913	1914					Average
	November	December	January	February	March	April	
Miles traveled	1250	1639	2516	2484	2712	2684	2214
Miles traveled per day	41	53	81	88	90	89	74
Gallons of gasoline used	500	680	805	823	780	765	725
Gallons of gasoline used per mile	0.40	0.414	0.32	0.33	0.288	0.285	0.33
Cost of gasoline per gallon	$0.17	$0.17	$0.17	$0.17	$0.17	$0.17	$0.17
Total cost of gasoline	$85.00	$115.60	$136.85	$139.91	$132.60	$130.05	$123.34
Cost of gasoline per mile	$0.068	$0.0705	$0.0543	$0.0563	$0.049	$0.048	$0.057
Gallons of gas engine oil used	20	26	36	43	31	27	31
Gallons of gas engine oil used per mile	0.016	0.0158	0.0143	0.0173	0.012	0.01	0.014
Cost of gas engine oil per gallon	$0.52	$0.52	$0.52	$0.52	$0.52	$0.52	$0.52
Total cost of gas engine oil	$10.40	$13.52	$18.72	$22.36	$16.12	$14.30	$15.82
Cost of gas engine oil per mile	$0.0083	$0.0082	$0.0082	$0.0089	$0.0059	$0.0053	$0.0075
Machine shop bill	....	$53.12	$27.07	$21.42	$18.00	$15.80	$22.56
Cost of repairs per mile	....	$0.0324	$0.0108	$0.0086	$0.0066	$0.0059	$0.0107
Total operative cost per mile	$0.0763	$0.1111	$0.0725	$0.0738	$0.0613	$0.0596	$0.075

which is owing to the fact that it has been impossible to obtain an accurate accounting from the Holton Interurban Railroad for wages paid to operators. The cost per mile for operators will vary in accordance with conditions of service and wage schedules of railroads in different localities throughout the country. A fair estimate of operators' cost would be a salary of $200 per month to motorman and conductor, which, on a basis of 150 miles operation per day, makes the cost per mile $0.044.

GAS-ELECTRIC LOCOMOTIVE

M. ST. P. R. & D. ELECTRIC TRACTION COMPANY MINNEAPOLIS, MINNESOTA

Cost of Operating Twenty-Eight Days in October, 1913,

Local Freight Service

(No repairs made during this period)

Motor spirits, 4954 gallons at $0.1168	$578.62
Gas engine oil, 146 gallons at $0.2158	31.50
Journal oil, 15 gallons at $0.0592	0.89
High test gasoline, 3 gallons at $0.2939	0.88
Wages (motorman, $106.50; conductor $106.50; brakemen (two) $120.00)	333.00
Total cost	$944.89
Locomotive miles	3438
Car miles	10730
Assumed weight of each car	30 tons
Weight of locomotive	56 tons
Car ton miles, 30×10730	321900
Locomotive ton miles, 56×3438	192100
Total ton miles	514000
Total cost of operation	$944.89
Cost per ton mile	$0.001835

Operating costs based on practically the same system of accounting and covering the operation of a total of forty-three gas-electric motor cars in 1915 have been received from eleven different railroads, including such representative systems as the Chicago, Milwaukee & St. Paul Railway, the Atchison, Topeka & Santa Fe Railway, the St. Louis–San Francisco Railway, the Chicago, Rock Island & Pacific Railway, and the St. Louis Southwestern Railway. The resultant average operating costs covering a total of 752,965 train miles are as follows:

GAS-ELECTRIC MOTOR CAR

	Average Cost per Train Mile
Fuel	5.4 cents
Lubrication	0.62 cents
Total repairs, labor and material	2.82 cents
All wages, including motorman, conductor, porter, brakeman, or trainman, when same are employed	8.85 cents
Cleaning car and equipment, including ice, coal, etc.	0.58 cents
Miscellaneous supplies	0.42 cents
Total cost	18.69 cents

(COPY)

Roseburg, Oregon
August 20, 1914

Mr. S. M. Mears, President
Ewbank Electric Transmission Company
Portland, Oregon

Dear sir:

Completed our fourth round trip today, total mileage 518.8

Used 150 gallons distillate at 6 cents	$ 9.00
10 gallons lubricating oil at 32 cents	3.20
5 gallons gasoline at 15 cents	0.75
	$12.95

for 518.8 miles, or 2½ cents per car mile—about 1 cent per car mile less than former run. Car is running fine and making time every day.

Yours very truly,
(Signed) H. B. Ewbank, Jr.

With the installation of an electric starter we anticipate a further reduction in cost per car mile amounting to at least ½ cent.

In the following comparative statistics the figures given for the steam train are average figures.

EWBANK MOTOR CAR

(3882 Miles)

80–3 Enginemen's salary	$190.20
81–1 Enginehouse expense	3.57
82–3 Fuel for motor cars	153.51
84–2 Lubricants for engine parts	86.60
85–2 Other supplies for engine parts	6.43
88–3 Trainmen's salary	257.96
89–6 Other supplies and expenses—motor cars	32.94
Total cost	$731.21
Total cost per mile	0.188
Fuel cost per mile	0.039

STEAM TRAIN (3882 Miles)

80–1 Enginemen's salary	$ 297.36
81–1 Enginehouse expenses	127.33
82–1 Fuel for locomotives	394.02
84–1 Lubricants for road locomotives	9.71
83–1 Water for road locomotives	50.02
85–1 Other supplies for locomotives	14.75
88–1 Trainmen's salary	341.23
89–1 Cleaning cars	23.55
89–2 Heating and lighting cars	13.45
89–3 Lubricating cars	2.21
89–4 Icing and watering cars	4.54
89–5 Other expenses	10.11
Total cost	$1288.28
Total cost per mile	0.332
Fuel cost per mile	0.101

MC KEEN GAS CARS

Cost per Mile

(Average for eleven months, ending May 31, 1914)

	All Cars of System	On One Section of Railroad
Fuel	6.01 cents	6.26 cents
Lubricants	0.25 cents	0.25 cents
Other supplies	0.54 cents	0.26 cents
Cleaning and washing	0.85 cents	0.49 cents
Motormen	3.71 cents	2.78 cents
Trainmen	5.71 cents	.... cents
Running repairs	6.02 cents	6.74 cents
Shop repairs	7.16 cents	2.48 cents
Accident repairs	0.45 cents	.... cents
Total	30.71 cents	23.83 cents

ACCELERATION RATES COMMONLY USED FOR TRAINS

	Miles per Hour
Steam Locomotives	
Way freight	0.1 to 0.2
Common passenger	0.2 to 0.5
Transcontinental	0.1 to 0.3
Electric	
Common freight	0.1 to 0.3
Through passenger	0.2 to 0.6
Local passenger	0.4 to 0.6
Electric motor cars	
Interurban	0.8 to 1.3
City	1.3 to 1.6
Rapid transit	1.3 to 1.8
Highest rates	2.0 to 2.5
Maximum rate used	
Coefficient of friction multiplied by 33.2	6.0 to 8.0

EQUIPMENT USED ON MOTOR CAR TRAINS

	Cars	Tons	Horse-power	Average Miles per Hour
Boston Elevated	6	202	2100	....
Manhattan Elevated	6	148	1000	14.7
Interurban	10	360	3360	23.0
Berlin-Zossen	1	101	1000	100.0

CONCLUSION

To draw a conclusion from the foregoing statistics does not seem to be a very difficult task, but to overcome the seeming prejudice against the internal-combustion engine in railroad circles is quite another thing, therefore a general survey of the internal-combustion engine is quite in place here.

Because of the rapid development of the internal-combustion engine in automobile, marine, tractor, and other fields, and the enormous production of such engines for use in the ordinary commercial life of the world, the principles of this form of prime mover are well known. It is used in all fields requiring motive power, and many applications of power owe their development to the economy and efficiency of the internal-combustion engine, so that whatever adverse criticism there may have been or is now is due to the mistakes and deficiencies of manufacturers rather than to the inherent principles and capabilities of the engine itself.

A comparison of the thermal efficiencies of internal combustion engines and steam locomotives follows. For all practical purposes British thermal efficiency can be taken.

Gasoline

Heating value of 1 gallon
62 Baumé gasoline....98200 B.t.u.
Average fuel consumption per hp. hour, $\frac{1}{8}$ gallon..............12275 B.t.u.

Steam

Heating value of 1 pound
bituminous coal......13500 B.t.u.
Average consumption per hp. hour, 3.43 pounds 46300 B.t.u.

	British Thermal Efficiency
Steam engines on test	14 per cent
Steam locomotives	5 per cent
Diesel crude-oil engines	25–35 per cent
Gas engines	30 per cent
Gasoline engines	15–25 per cent

The Diesel crude-oil engines show the highest efficiency, their only drawback at the present time being their complicated and numerous parts. However, crude oil in the internal-combustion engine is in quite general use at present and the extent of its introduction into general use is very little appreciated. Whether we use crude oil directly in the cylinders of the internal-combustion engine or use it in making fuel gas—and in whatever manner we make the gas—there is no question that the generation of power in large quantities from this class of fuel can compete commercially with the production of electricity from water power. The internal-combustion engine is from two to five times as economical in the use of coal, gas, or crude oil as the steam engine, and a power plant equipped with such engines has an economy that it is absolutely impossible to secure with the steam boiler and compound condensing engines, even by the use of the best methods of operation.

The tendency of the self-contained motor car of today is still along the lines of the early electric cars, that is, to place the transmission machinery and motive power—first the electric motors and now the gas engine—inside the car body and to transmit the power to the driving wheels through some form or other of transmission; it must not be lost sight of that these wheels have a certain vertical and lateral motion or, to be correct, the car body and truck frames have the motion in respect to the wheels, owing to the spring suspension and the play in the brasses. It seems strange that designers follow out the same practice used in other machines *instead of designing for the problem in hand.* Perhaps this may be owing to the fact that the gas-engine designer is usually unfamiliar with railroad conditions and thinks what applies to the automobile should apply to the self-contained car. Moreover, the railroad-truck and car-body designers know next to nothing about the gas engine and endeavor to adapt whatever equipment is supplied to them. Furthermore, the designers of these two separate units do not seem to be able to get together and design in a logical manner. The future internal-combustion engine propelled motor car and locomotive must be designed by an engineer who can and does comprehend the duties that are placed upon railroad motive power. Scientific work in conjunc-